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FACILITATING THE EXPLOITATION OF ERTS-1 IMAGERY USING SNOW ENHANCEMENT TECHNIQUES

141

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16. Abstract This investigation has demonstrated that fracture analysis can be effectively conducted using snow cover as an enhancement medium. Snow cover in combination with low angle solar illumination heightens the tonal contrast between surface features and increases the data yield of low resolution imagery. Identical fracture systems are more detectable in winter than in other seasons because of a contrasting surface medium (snow) and a relatively low sun angle. The enhancement provided by snow cover may be broadly categorized as (a) reduction of background "noise", (b) increased shadow contrasts, (c) enhanced vegetative cover differences, and (d) diagnostic melt patterns. Heavy snow cover (e.g., >4 inches) generally accentuates geological features with major topographic expression; lighter snow cover (<4 inches) generally accentuates fractures and land use differences.

Snow enhancement interpretation techniques can be integrated into an operational procedure for geological field mapping; sample maps were prepared which represent interim steps in the geological mapping process (e.g., the ERTS Fracture-Lineament Reconnaissance Map). Wintertime imagery acquired in a systematic manner justifies repetitive ERTS coverage for geological studies.

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PREFACE

The primary objective of this ERTS investigation has been to evaluate the effectiveness and utility of snow-cover (and the monitoring of progressive snow-melt and accumulation patterns) as a photogeological enhancement technique. The results and conclusions discussed here are based on the use of ERTS imagery as the primary data source. Large and small scale aircraft coverage were used to confirm the results derived from analyses of ERTS data.

This experiment demonstrated that snow enhancement interpretation is a useful and valid technique for fracture analysis and tectonic mapping from low resolution ERTS imagery.

The investigators found that, snow-cover variations increase the detectability of lineaments and other geological phenomena because: (a) snow provides a homogeneous cover to reduce minor soil or vegetative tonal variations which otherwise increase background "noise"; (b) snow increases the contrast of shadows resulting from slight topographic variations; (c) tonal contrasts between bare (snow free), and vegetative (snow obscured) fracture traces and surrounding snow-covered terrain are accentuated; and (d) snow melting is accelerated in moist zones and therefore provides an indirect measure (dark toned signature) of moisture/thermal properties serving to emphasize subtle lithological changes.

This report contains the results of ERTS image analysis of snow-free and snow-covered terrain in the New England area. Complementary analyses were conducted utilizing radar imagery, U-2 aircraft color infrared photography and aeromagnetic and geological data for two test sites. Snow enhanced ERTS imagery was found to complement, rather than duplicate, the information provided by radar imagery.

The test areas for this investigation were selected because of their geologic complexity, i.e., an area of complex tectonics covered by glacial drift (New England Test Area), and a geologically complex area covered by deep residual soils in the Piedmont of Maryland and Virginia. The selection of these areas also provided the opportunity to contribute new tectonic data. The volume of fracture detail detected on snow-free and snow-covered ERTS imagery of the New England Test Area exceeded the number of mapped fractures from existing sources. Within the New England Test Area the same fracture systems were less readily detectable in the autumn, spring or summer because of the lack of a contrasting surface medium (snow) and a relatively high sun angle.

Field work established a strong correlation between the major fracture-lineament directions interpreted from snow-free and snow-covered ERTS imagery and the strike of bedrock joints recorded in the field. This supports the conclusion that the interpreted fracture-lineaments are surface expressions of bedrock structure.

Additive color presentations, density slicing, isodensity processing, optical edge enhancement, film sandwich and Ronchi grating were used for fracture analysis to determine if they provide enhancement in addition to that provided by snow cover and low angle solar illumination. The film sandwich, additive color, and isodensity processing contributed the greatest amount of fracture information of any of the supplementary techniques evaluated but did not significantly increase the amount of data supplied by visual analysis of snow enhanced imagery.

The techniques developed in this experiment make the use of ERTS wintertime imagery more productive not only for mapping, but also for a variety of multidisciplinary applications. Research leading to development of snow enhancement techniques has progressed rapidly to practical applications, and to developing a system for early practical use of snow enhancement for geological mapping, (i.e., analysis of ERTS snow enhanced imagery in the context of operational field mapping programs).

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1.0 INTRODUCTION

Snow enhancement is the accentuation of various features on the Earth's surface resulting from the differential accumulation or melting of snow cover or by the increasing contrast provided by snow cover in accentuating vegetative or topographic differences. In this report, principal emphasis is directed to geological applications of snow enhancement.

The investigators hypothesized that imagery of snow-covered terrain was an under-utilized source of photogeological data and that the technique of snow enhancement interpretation could have particular value for analyzing relatively low resolution imagery acquired by ERTS systems. It was also hypothesized that the repetitive coverage of ERTS-1 would make it possible to monitor variations of snow-cover to evaluate the effects of differential melting on fracture detection.

Our evaluation of a variety of viewing techniques to further increase the natural enhancement provided by snow cover and low angle solar illumination indicates that several of these do increase fracture detectability. Recommendations for the use of these techniques are contained within this report.

Operational procedures for using snow enhanced ERTS imagery within the context of a field mapping program were developed. Fracture-lineaments confirmed through the sequential system of validation developed by the investigators are displayed on a 1:250,000 scale ERTS mosaic of western Massachusetts. The mosaic increases the quantity of structural data now available for this area. A 1:1,000,000 structural map of the entire New England Test Area and several maps of selected test sites were also prepared. These maps are a source of information which may be used for updating existing structural maps.

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2.0 BACKGROUND

2.1 Concept of Snow Enhancement

Geological structure and lithology exert a strong influence on surface relief. Fractures (joints and faults) are usually more easily eroded than surrounding rock, producing linear to curvilinear surface depressions. In this report, emphasis is directed to the enhancement of geological features and especially fracture traces by snow patterns. On snow-covered imagery, fractures stand out in contrast to surrounding terrain because: (a) snow provides a homogeneous cover to reduce minor soil or vegetative tonal variations which otherwise increase background "noise"; (b) snow increases the contrast of shadows resulting from slight topographic variations; (c) tonal contrasts between dark toned bare (snow free), and vegetative (snow obscured) fracture alignments and surrounding light toned, snow covered terrain are accentuated; and (d) snow melting is accelerated in moist zones and therefore provides an indirect measure (dark toned signature) of moisture/thermal properties serving to emphasize subtle lithological changes. Fracture zones tend to have a high moisture content and high heat capacity, therefore snow melts off of fracture zones more rapidly than surrounding materials.

The grey scale variations normal in satellite imagery of snow-free terrain constitute the background against which the (linear) pattern of radiometric contrast representing a fracture feature must be detected. When the lineament itself is very subdued in its radiometric expression it may be only barely detectable against that background. One may say for this relationship that the "signal" is nearly lost in the background "noise". Snow cover tends to improve the detectability in two ways. First, it suppresses the background noise: for example, the mottled appearance of grass-covered areas is replaced by the radiometrically more uniform character of the snow-cover. Second, it accentuates the contrast by an absence of snow cover along the fracture, due largely to the thermal effect of (high heat capacity) water in the fracture zone. Thus, the effects of reduction in background grey-scale variation (noise) and increased detectability result in a lowering of the threshold of detection for such fracture features. Since many structural features have only the most subtle topographic expression, snow enhancement in many cases greatly increases the potential for photogeological interpretation.

2.2 Literature Review

Analysis of Mercury, Gemini, and Apollo imagery over the past five years, including that by Lowman (1967) and Wobber (1969), demonstrated useful applications of small scale photography to the resolution of geological, hydrological and environmental problems. The synoptic nature of orbital imagery and its value for geological structural analysis are reasonably well understood and have been studied in detail by Lowman (1970), and discussed by Hamilton (1971). Wobber (1972) cited the value of imagery acquired from manned spacecraft for earth resources satellite mission planning.

Woloshin (1965) and Lowman (1967) used Nimbus photography with snow cover to detect the extension of a fault in the East Sayan Mountains of the USSR. Wobber (1969) suggested that low angle solar illumination could have value in snow-covered glacial terrain. Reports by Sabatini and Sissala (1968) and Sabatini et al. (1970) included references to the fact that geological lineaments, hydrological features and outcrop patterns were sometimes enhanced by snow. The value of Nimbus imagery for detecting major structural features was noted by Lathram (1972). He reported the discovery of several previously unmapped fractures and faults in Alaska and western Canada utilizing Nimbus imagery of heavily snow-covered terrain.

Using Gemini photographs, Wobber (unpublished studies, 1970-1971) determined that snow cover contributed to fracture enhancement and accentuated some lithological differences. Lowman (personal communication, 1972) also observed that the presence of snow cover enhanced structural features as seen in Apollo photographs. Nicks (1970) noted from interpretation of Apollo photographs that snow sometimes enhanced fracture patterns.

Recently, W.D. Carter (personal communication, 1972) of the U.S. Geological Survey observed a circular feature on Apollo-9 photographs of snow-covered terrain in Southeastern Arizona. Following geological and geophysical studies, Bromfield, et al. (1972) judged that the circular feature was a result of a favorable sun angle and shadowing caused by an intersecting fault pattern.

2.3 Pre-ERTS Investigations

Aerial photography of snow-covered, non-polar terrain is generally difficult to obtain. Photographs of snow-covered terrain in temperate areas, obtained during winter military exercises, are usually classified and unavailable for geological study. Between 1965 and 1970, the Principal Investigator collected oblique color photography of recently snow-covered areas in the central and northwestern United States. These isolated photographs were collected under conditions of relatively high angle solar illumination and unknown snow depth. Bedding planes, sedimentary versus volcanic rock and probable fracture systems appeared to be enhanced. This work confirmed the utility of oblique imaging as a tool for fracture detection in snow-covered terrain. The working limitations of the technique, however, could not be established. Lacking repetitve coverage, enhancement of structural details by differential snow melt patterns could not be tested.

Available ERTS-analog (Mercury, Gemini, Apollo, Nimbus) and ERTS-simulation imagery of snow-covered terrain was selectively analyzed by the investigators in preparation for receipt of ERTS-1 imagery. These studies suggested that fractures on small scale (low resolution) Apollo photography could be detected more speedily in snow-covered terrain. These studies were limited to comparative analysis of adjacent snow-covered and snow-free areas on the same orbital photograph, and therefore, the results could not be considered conclusive. In the absence of repetitive photographic coverage, determining whether monitoring progressive snow cover changes would yield even more significant information could not be tested.

In anticipation of ERTS-1 imagery, an intensive analysis of snow-covered terrain in the Feather River area of California was conducted utilizing ERTS simulation (U-2) imagery (Figure 1). Four sequential flights[1/] of this multiband imagery were analyzed to assess the value of snow enhancement as a photogeological technique. Each of the four bands was systematically analyzed and broad categories of data yield were identified. Band 1 (475-575nm) was determined to yield the least data. Band 1 images were low contrast, hazy images which were only marginally satisfactory for photogeological analysis. Band 2 (580-680nm) had the highest contrast, clearest appearance and provided the maximum detail. Band 3 (690-760nm.) provided the same basic information as that of band 2, although not with the same clarity or acuteness. The color infrared band (150-900nm.) was over-exposed for snow-

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1/ Imagery was acquired on the following dates: 8 December 1971, 20 December 1971, 31 January 1972 and 6 March 1972.

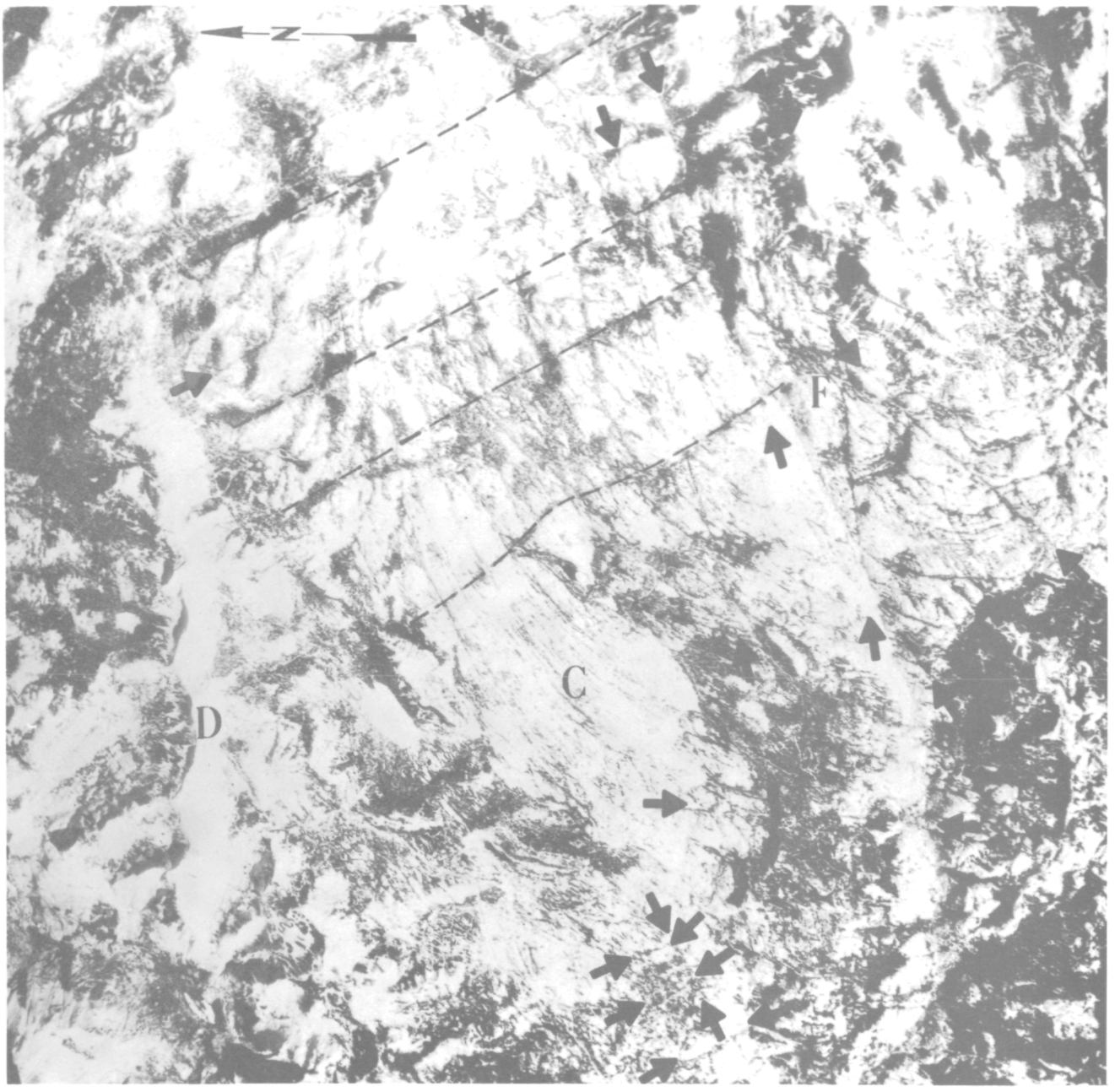

Figure 1: 70mm (580-680nm. band) 1:165,000 scale enlargement of the Elephant Rock area south of Lake Tahoe, California. The photography was acquired on January 31, 1972 by U-2 ERTS simulation aircraft. Snow cover which is extensive over the photograph accentuates crescentic fracturing patterns at (C). Apparent cross-faulting (F) and significant fracture patterns (solid black arrows) can be identified. These fracture patterns are more conspicuous because of the tonal contrasts present between the dark tones of fracture lineaments and white tones of surrounding snow-capped outcrop areas. Major geological trends, the origin of which has not been determined, are noted by dashed lines. The lineaments which were delineated did not appear on available geological maps of this area. Aeolian snow alignments were detected with magnification. No difficulty was experienced in distinguishing snow (wind) alignments and snow drift banks (D) from fracture lineaments.

covered areas; its data yield could not be fully determined. However, it did provide unique information for the discrimination of vegetative cover which was sharply contrasted against a snow cover background.

The analysis of ERTS-simulation imagery established that the 580-680nm. bandpass provided the greatest overall fracture detail. This correlates directly with ERTS-1 RBV band 2 (580-680nm.) and closely to ERTS-1 MSS band 5 (600-700nm.). Indications of the geological usefulness of ERTS-1 MSS bands 6 & 7 for imaging snow-covered terrain could not be directly determined.

2.4 Use of Snow Enhancement by Other ERTS Investigators

During the experiment, other investigators confirmed the general value of snow cover for enhancing various natural and cultural features.

Isachsen, et al. (1973) found that certain glacial features, including individual drumlins, were best seen in winter imagery. This was attributed to the fact that the snow cover obliterates many land use patterns and the low winter sun angle highlights relief of the drumlins. Moore and Gregory (1973) emphasized the importance of seasonal variations for enhancing the detectability of geological features. They reported that snow cover helped enhance morainal materials by eliminating other terrain "noise"; they found a residual snow cover to be an effective enhancement factor.

Brown, et al. (1973) indicated that January Band 7 imagery provided sufficient snow enhancement of shadows at low sun angles to allow separation of various cultural features. They concluded that snow enhancement had value for land use classification and provided a better basis for mapping urban housing densities and rural population distributions.

Breckenridge, Marrs and Murphy (1973) noted that snow-cover provides great enhancement of urban areas in Wyoming. Not only does the snow mask all contrast in rural areas and increase the contrast between urban areas and their surroundings, but it provides a means of obtaining a pseudo-thermal map that records intensity of cultural activity in remarkable detail. They report that interpretations of isodensity contour maps from these winter ERTS images compare very favorably with

interpretations of comparable aircraft photography and provide considerable data for updating most city maps.

Miller and Belon (1973) report that animals winter in loose aggregations of several hundred to a thousand and such aggregations typically remain in a drainage area and feed intensively before moving on . There also is some evidence that caribou wintering areas thus disturbed, melt-off much sooner than other areas. Trampling activities of the herds cause early snow melt by a premature exposure of vegetation, a decrease in spectral reflectance, and a disturbance of the natural surface.

Clapp, et al. (1973) reported that September ERTS imagery was better than July imagery for wetlands discrimination, but snow-covered imagery (13 December 1972) proved superior to September imagery for discrimination of certain wetland communities.

3.0 PROGRAM DESIGN

3.1 Specific Objectives

It was hypothesized that the analysis of snow cover patterns and changes (snow melting) could increase the utility of small scale low resolution imagery for geological analysis. Using the unique capabilities of repetitive ERTS coverage over the target area for monitoring snow cover variations, the objectives of the experiment were:

- To test the effectiveness and utility of snow enhancement for geological fracture mapping.
- To test snow enhancement as a technique for seasonally extending the utility of low resolution ERTS imagery for geological studies.
- To define the most useful bands (multispectral black and white, reconstituted color) and interpretation procedures for geological studies of snow covered terrain.

An important objective was the demonstration of snow enhancement for practical geological applications: These applications include providing basic data for field geological mapping, mineral exploration, ground water resources development, and prediction of excavation and tunneling problem areas.

3.2 Rationale for Test Area Selection

3.2.1 Selection of Test Areas

Factors considered in the selection of test areas include (1) diversity in general terrain and climate, (2) difficulty of acquiring fracture data, and (3) the potential to contribute new data to current geological programs. Areas of temperate climate, with maximum opportunity to observe seasonal snowfall and melt variations were given a high priority. A diversity of terrain types, e.g., glaciated vs. unglaciated, was judged useful for fully evaluating the advantages and limitations of the technique.

Based on these factors, two areas were selected as primary test areas -- New England and Maryland-Virginia. A matrix was prepared (Table 1) to facilitate comparison

TABLE 1: TEST AREA COMPARISON MATRIX[1/]

GENERAL CHARACTERISTIC		NEW ENGLAND TEST AREA	MARYLAND-VIRGINIA TEST AREA
Regional Bedrock Geology		Triassic sediments and intrusives — schists, gneisses and marbles intruded by granitic and alkalic rocks	Triassic sediments and intrusives — schists, gneisses, and marbles intruded by granitic and alkalic rocks
Structure		regional strike N20E-many regional normal and thrust faults	regional strike N30E-no major thrusts known-some large normal faults
Geomorphology		Dissected and glaciated peneplain on complex structured metasediments and intrusives; monadnocks	Sub-maturely dissected and weathered peneplain (piedmont) on crystallines and folded sedimentary formations, some residual ridges; sloping, terraced coastal plain, with submerged border
Relief		0-2000 feet	0-1000 feet
Landforms		till plains, kettle-kame moraines, drumlins, large alluvial flood plains and terraces, glacial outwash	small alluvial floodplains and terraces, deeply weathered piedmont plain
Soil Texture		medium-coarse (sandy)	fine-medium (clayey)
Native Vegetative Cover		deciduous and coniferous	predominantly deciduous
Snowfall	Mean Annual	32-64 in.	8-32 in.
	Annual Days	10-20 days	5-10 days

[1/] Descriptive terms reflect broad characteristics of the area.

of areas selected as primary test areas. An absence of snow cover in the Maryland-Virginia Test Area during the 1972 - 1973 period prevented studies in this area and eliminated the opportunity to test snow enhancement within an area of deep residual soils.1/

3.2.2 New England Test Area

The New England area (southern Vermont and New Hampshire, Massachusetts, Connecticut, and Rhode Island) is well suited for studies of snow enhancement. The complex and varied geology of this region provides the opportunity to study the enhancement of geological structure in many different lithological types within a relatively small area. The high degree of deformation (thrusting, complex folding, and metamorphism) makes this an excellent area for studying complex fracture systems which might otherwise be difficult to detect.

The extended periods of snowfall of various depths also an important consideration in the selection of the New England area. The area has an average of more than 15 days of snowfall per year providing ample time to collect both ERTS and underflight imagery and to conduct field checking. Snow cover, which ranges from light to moderately heavy, affords the opportunity to study fractures under various depths of snow cover.

The United States Geological Survey's cooperative program with Connecticut, Vermont, New Hampshire and Massachusetts involves mapping of bedrock and surficial geology for 7 1/2-minute quadrangles. Aeromagnetic surveys (Figure 2), mineral resource studies, hydrologic studies, and shallow seismic surveys are also being conducted. Radar imagery for Massachusetts and Connecticut was available for use in comparing lineaments derived from ERTS imagery with the topographically-expressed lineaments on the SLAR imagery. Relatively few quadrangles, however are available for public use and some state geologic maps are out of date. It is anticipated that this investigation will contribute useful, new fracture data for current mapping programs while simultaneously refining a new photogeological technique.

1/ The investigators (in consultation with the monitors) increased the detail of analysis for the New England Test Area. The specific rationale used for selection of the Maryland-Virginia Test Area and a geological description of the area are included in APPENDIX D for completeness.

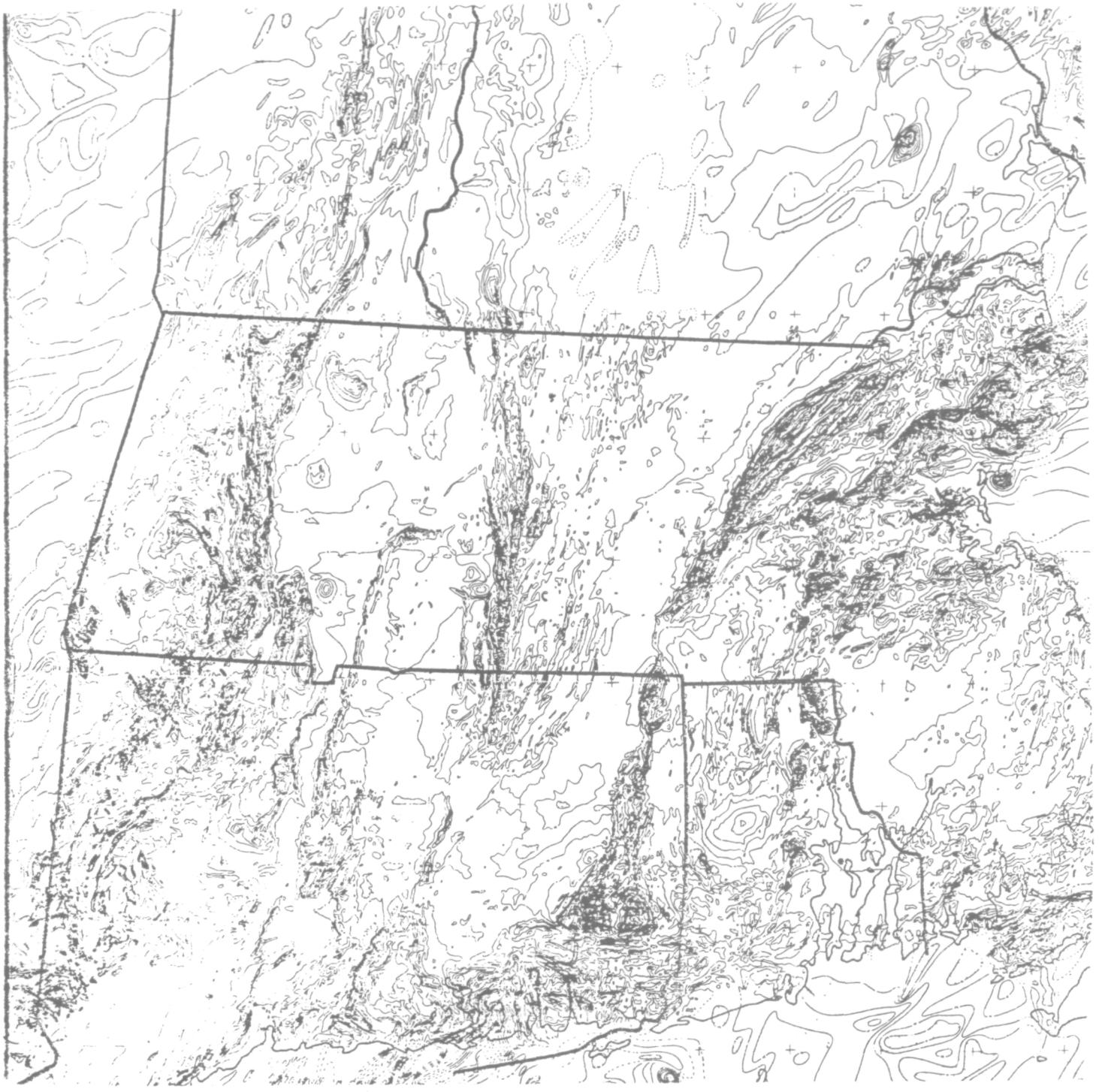

FIGURE 2 : Aeromagnetic intensity map of southern New England with a magnetic contour interval of 100 gammas. The aeromagnetic data reflect the gross lithology and structure of the area. Aeromagnetic lineaments identified using 1:250,000 scale sections of this map were compared with lineaments interpreted from ERTS imagery as an additional check on their structural validity. Coincidence of aeromagnetic lineaments with fracture-lineaments interpreted from ERTS imagery may indicate mineralized fracture zones (Source: USGS).

3.3 Test Area Description

The New England Test Area extends from 72° to 74° west longitude and from 41°31' to 43° north latitude (Figure 3). It includes portions of Connecticut, Massachusetts, southern Vermont and New Hampshire. Regional topography is largely controlled by bedrock structure and lithology although glaciation has modified the landscape. More than 90 percent of the test area is covered by unconsolidated surficial deposits, including residual soil, alluvial terraces along streams and rivers, colluvium, and various glacial deposits. Glacial drift occurs over most of the area. The general southeasterly direction of ice movement in the New England Test Area is illustrated in Figure 17.

The southern New England area is divided into five physiographic provinces. Each province offers a unique set of geological conditions for the purposes of this experiment (Figure 4). The provinces from east to west are:

(1) Coastal lowland on the east coast (low topographic relief).

(2) Eastern upland extending from the Connecticut coast to northern New Hampshire (moderate relief, crystalline bedrock).

(3) Connecticut River Valley (graben, etc.)

(4) Western upland which includes the Berkshire & Green Mountains.

(5) Taconic Mountains along the western borders of Connecticut and Massachusetts (thrust-faulted area).

The Coastal Lowland is principally underlain by the Dedham granodiorite which has been intruded by younger granite and diorite (Emerson 1916). Carboniferous conglomerate, sandstone, and shale overlie the granodiorite in a series of down-faulted sedimentary basins: the Narragansett, Norfolk, and Boston basins extending from Providence, Rhode Island to the Boston area (Figure 4). The granodiorite is overlapped in the Cape Cod area by Tertiary and Quaternary coastal plain sediments.

The bedrock geology of the Eastern province is dominated by the Bronson Hill anticline (Robinson, 1967), a complex zone of gneiss domes and recumbent folds extending for a distance of 150 miles from Long Island Sound to Northwestern Maine. This region structure lies near the center of the Appalachian tectonic belt of New England and has undergone intense late Devonian Acadian deformation and metamorphism.

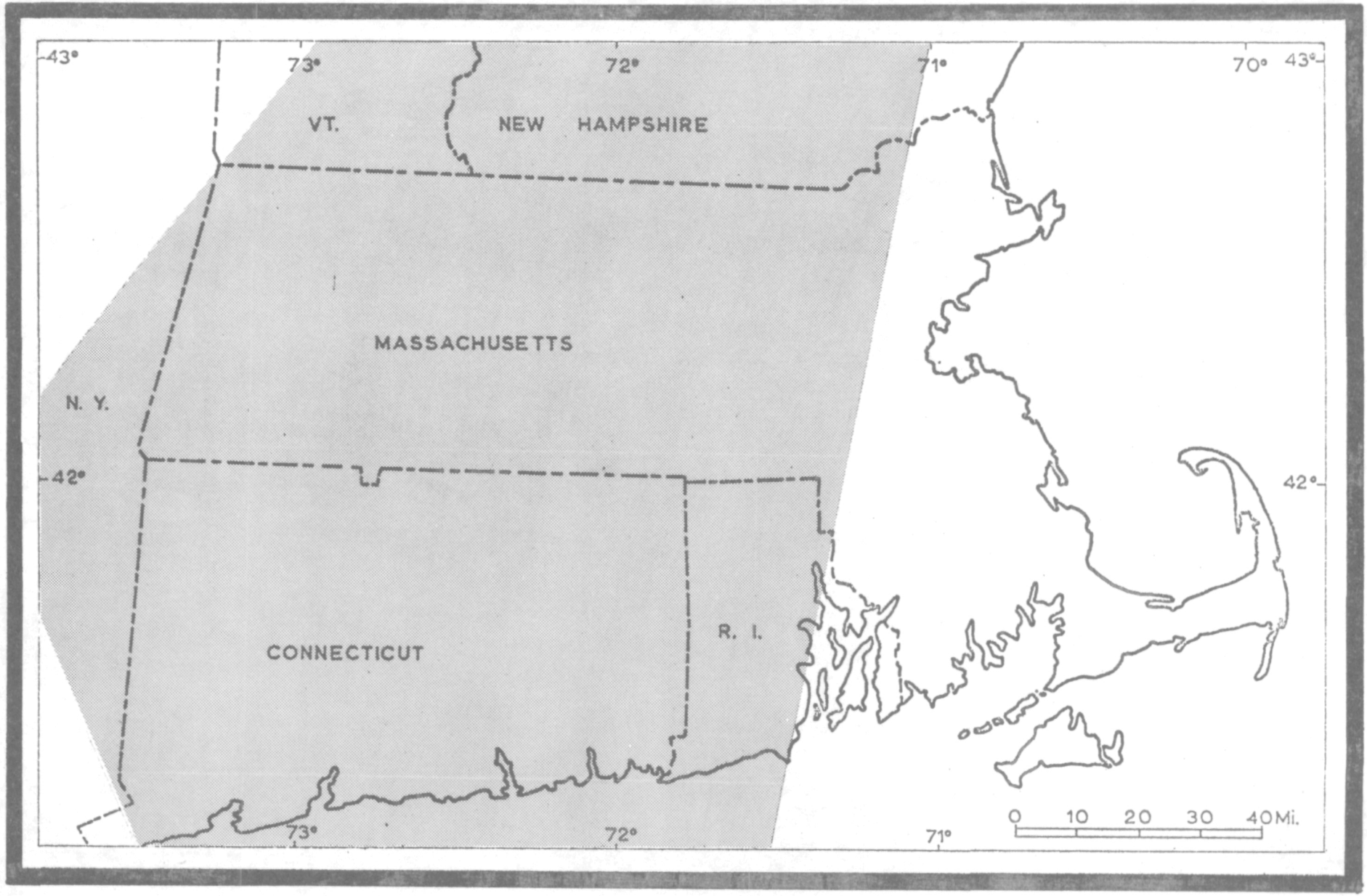

FIGURE 3: ERTS-1 New England Test Area

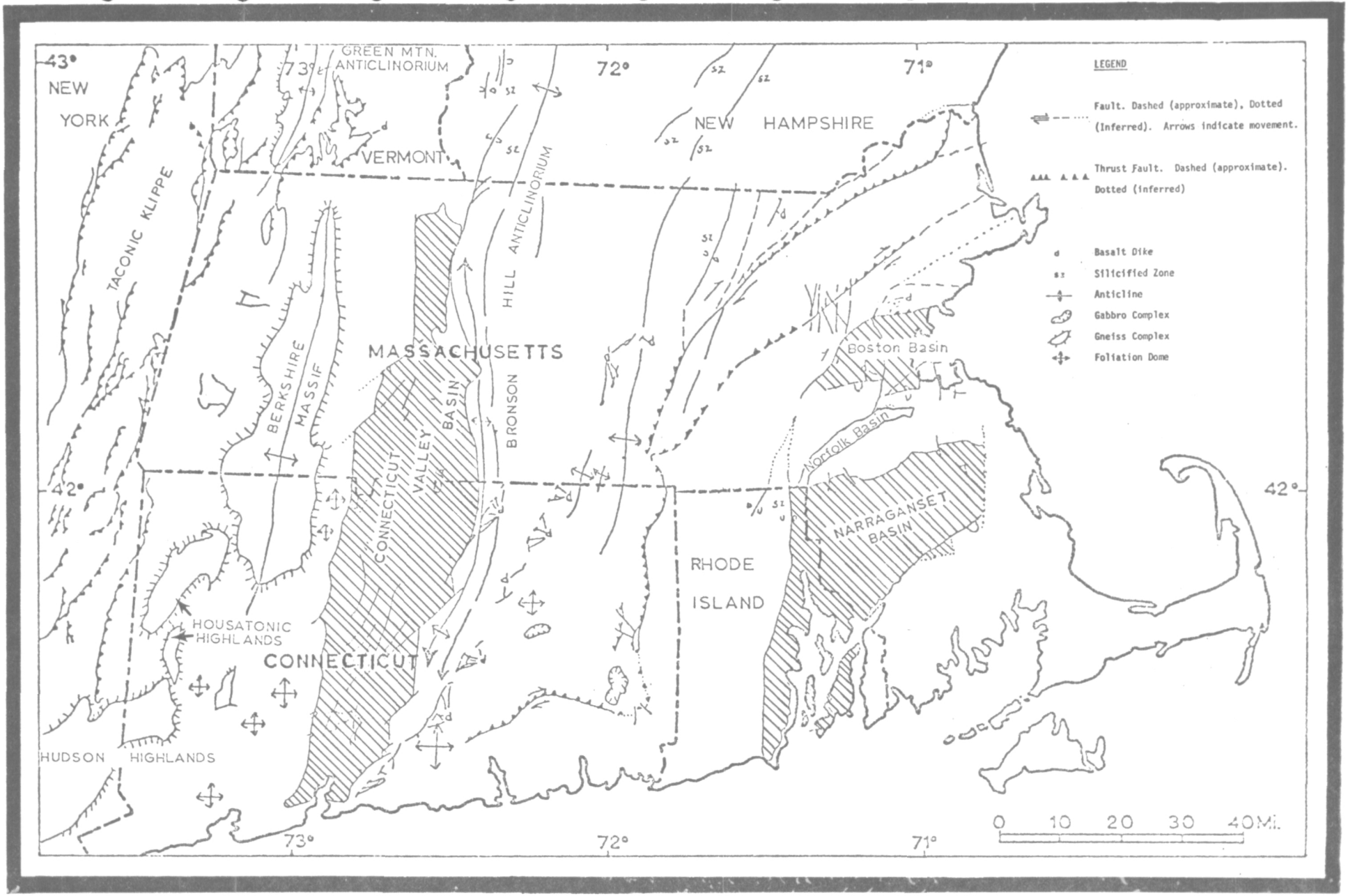

FIGURE 4: Tectonic Sketch Map of the New England Test Area
(Modified from Skehan, 1967 in "Economic Geology in Massachusetts, Univ. of Mass. publication)

The Bronson Hill anticline is an important feature in New England geology because it contains a well defined sequence of metasediments of Ordovician, Silurian, and Devonian age that have been dated in part by fossils. This metamorphic sequence overlies a series of Precambrian coarse-grained gneisses which are exposed in the cores of the gneiss domes and overturned anticlines (Robinson, 1967).

The valley of the Connecticut River in Connecticut and Massachusetts is principally underlain by Triassic rocks confined to an elongate basin which extends from Long Island Sound to the vicinity of the Massachusetts-Vermont boundary. The basin contains a series of eastwardly-dipping non-marine conglomerates, sandstones, and shales with three interlayered basalt and diabase sills. The middle sill, the Holyoke diabase, is 400 feet thick in some areas.

The basin is bordered on both sides by faults, and is thus a graben. The eastern fault or Great Fault is the longest and has an estimated throw of 17,000 to 35,000 feet. The Triassic beds which dip eastward into the Great Fault, were formed by a series of coalescing alluvial fans (Eardley, 1962).

The Western Upland province includes the Berkshire and Green Mountains. It extends from the Connecticut River Valley to the eastern front of the Taconic Mountain Range. The core of this area is made up of Precambrian granites and gneisses which are overlapped on the flanks by quartzites of Cambrian age. This Precambrian core stood as a topographic and structural high over which the Taconic thrust sheet supposedly moved from its rooted position in eastern Connecticut, Massachusetts, and New Hampshire (Eardley, 1962). On the east flank of the core are eugeosynclinal facies metasediments, including Cambrian and Ordovician schists and amphibolites, Middle Ordovician carbonaceous schists and slates, Silurian quartzite, and Lower Devonian schists and marble. Most of these strata are of the garnet and staurolite metamorphic grades and are compressed into a series of tight isoclinal folds, many of which are cut by both normal and reverse faults.1/

The Taconic Range is a series of low mountains and hills composed chiefly of argillaceous rocks such as phyllite, slate, and shale which have been folded into a large synclinorium. These clastic rocks are surrounded in the adjacent lowlands by carbonate rocks (Rodgers, 1959). The Taconic sequence contains three slate formations of Ordovician age and eight Cambrian

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1/ Associated with the Berkshire core are north-south elongate, infolded belts of Cambro-Ordovician limestone which have controlled the location and orientation of major (Housatonic River) and minor or tributary valleys (e.g., Aspetuck), and of lesser topographic features.

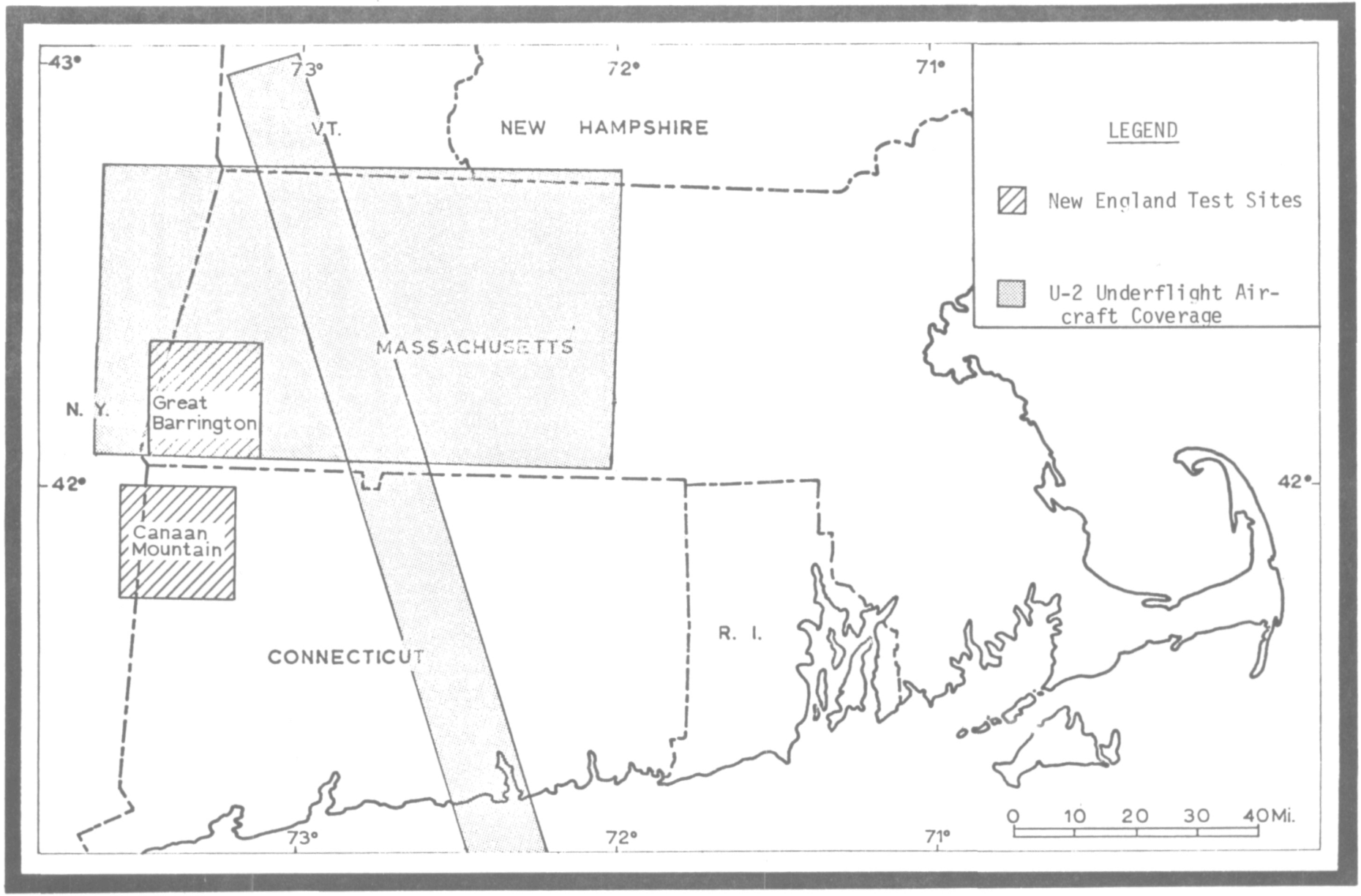


FIGURE 5: Location of New England Test Sites and Underflight Aircraft Coverage

formations of Ordovician age and eight Cambrian formations of slate, phyllite, quartzite, and limestone. The Cambrian and Ordovician strata of the Taconic mountains lie beside Cambrian and Ordovician rocks of the surrounding valleys; however, the two groups of rocks have no features in common except age (Eardley, 1962). These relationships have resulted in a long controversy concerning the interpretation of the Taconic clastic sequence as a klippe representing an eastern eugeosynclinal facies that has been thrust westward 30 to 50 miles over the western trough sequence. The miogeosynclinal carbonates of the western trough supposedly are part of the autochthonous rocks.

3.4 Selection of Test Sites

3.4.1 Rationale

An intensive anaylsis of the New England Test Area resulted in the selection of two primary test sites, Great Barrington, Massachusetts and Canaan Mountain, Connecticut (Figure 5). The sites were chosen from areas with (1) abundant snow cover (2) complex geological structure and (3) subtly expressed bedrock jointing. Additionally, the limitations of existing geological data were evaluated in an effort to select areas where new geological data could be contributed.

For each test site, a detailed geological analysis was conducted utilizing a variety of available remote sensing records including snow-covered and snow-free ERTS imagery, with supplementary studies of high altitude aircraft color infrared imagery CIR (as available), SLAR and aeromagnetic data. These data were analyzed and the results correlated with field geological observations. Techniques refined from these analyses served as guidelines in fracture-lineament mapping for the remainder of the test area and are documented in the NDPF Users Manual. The results of a multisensor analysis of both sites are discussed in section 5.4.

3.4.2 Great Barrington, Massachusetts Test Site

The Great Barrington site (Figure 5) is located in Western Massachusetts and bounded by coordinates 73°05' - 73°20'W and 42°10' - 42°25'N. The area includes a portion of the western edge of the Berkshire Mountains on the east and segments of the Taconic Mountains on the west.

The Great Barrington Test Site lies along the western front of the Berkshire Massif, a Precambrian core of igneous and metamorphic rocks which have been thrust westward over

Cambrian and Ordovician metasedimentary rocks (Figure 6). The western edge of the Berkshires is defined by a thrust-fault. The feature creates a prominent regional topographic break since the rocks of the massif are considerably more resistant to weathering than the adjacent marble of the Stockbridge - Great Barrington Valley. Several smaller ridges are isolated thrust-faulted remnants of more resistant rock including the Cheshire Quartzite and Everett Schist.

At least three major episodes of tectonic activity have altered the rocks of this area. The earliest episode (Grenville orogeny) involved igneous intrusion, high-grade metamorphism, and development of folds and faults in a northeasterly trend. Subsequent to deposition of the Middle Ordovician Walloomsac Schist, the Precambrian and lower Paleozoic rocks were deformed (Taconic orogeny) into a series of tight folds.

Major thrusting moved both the Taconic Mountains and the Berkshire Massif to their present positions. The latest episode (Acadian orogeny) involved high-grade regional metamorphism and granitic intrusion.

3.4.3 Canaan Mountain, Connecticut Test Site

The Canaan Mountain site (Figure 5) is located in northwestern Connecticut and is bounded by coordinates 41°45' - 42°00'N and 73°15' - 73°30'W. The area includes portions of the western edge of the Berkshires (Housatonic Highlands) on the east, and segments of the Taconic Mountains on the west.

The major structural elements of the Canaan Mountain area include the Housatonic Highlands, the Canaan Mountain salient, and the Taconic Mountains and surrounding lowlands (Figure 7). The Housatonic Highlands are a southward continuation of the Berkshire Massif, a large anticlinal uplift exposing Precambrian rocks. The Housatonic Highlands consist primarily of Proterozoic granite-gneisses and interlayered metasedimentary rocks. Outliers of Cambrian Poughquag Quartzite are contiguous with the westward thrusted Proterozoic rocks and overlay slivers of middle Ordovician carbonates.

The Berkshire-Housatonic trend is interrupted by Canaan Mountain which is a salient of middle Ordovician schists of the Berkshire (=Manhattan) and Waloomsac formations. The Canaan Mountain salient has been variously interpreted as being in fault contact or conformable with the surrounding strata (Rogers, 1959). The Berkshire-Housatonic rocks are bounded on

Figure 6: Geologic Map of the Great Barrington, Massachusetts area. From Albany 1:250,000 scale Geological Sheet, New York Geological Survey. Location of area shown on map to the right.

EXPLANATION

Owl	Waloomsac schist	Ordovician
Ocst	Stockbridge marble	Cambrian
Ccd	Cheshire quartzite	
C_{ev}	Everett schist	
mu	Undivided metasediments	Precambrian
am	Amphibolite	
bg	Biotite granitic gneiss	

Thrust fault - teeth, overthrust block

High-angle fault

Lithologic contact

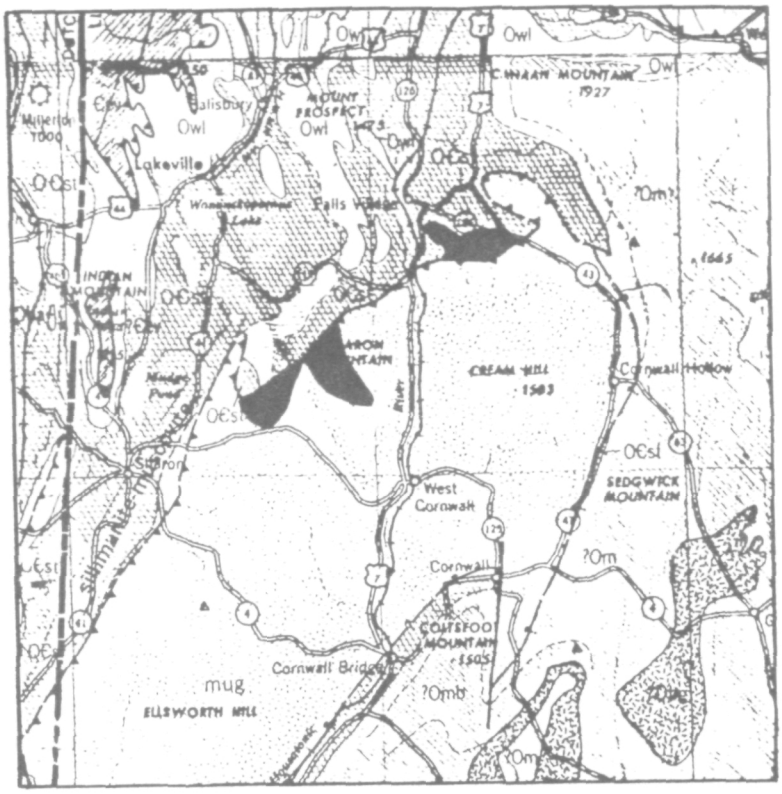
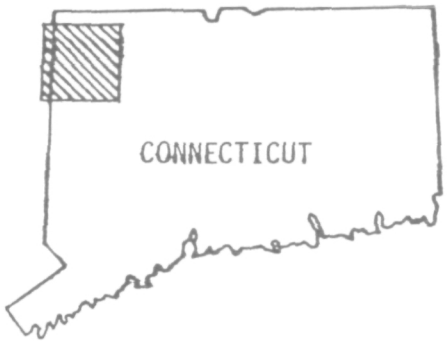


Figure 7: Geologic Map of the Canaan, *Connecticut area. From Albany and Lower* Hudson 1:250,000 scale geologic map sheets, New York Geological Survey. Location of area shown on map to the right.



EXPLANATION

Dbg	Biotite granite gneiss	Devonian
Owl	Walloomsac schist	Ordovician
Om?	Manhattan ? schist	
OEst	Stockbridge marble	
	Poughquag quartzite	Cambrian
€ev	Everett schist	
mug	Undivided mixed gneisses	Precambrian

Thrust fault, teeth on overthrust block

High-angle fault

Lithologic contact

the west by thrust faults indicating westward movement of the Berkshire trend over the rocks of the Taconic synclinorium. A thrust fault is also postulated along the eastern edge of the Housatonic Highlands, forming a fenster or structural window. The Taconic synclinorium consists of a series of Cambro-Ordovician schists and quartzites which have been thrust westward (probably from the eastern side of the Berkshire Massif) over marbles (Stockbridge marble) of similar age and downfolded into a complex series of synclines containing both autochthonous and allochthonous strata.

In addition to the complex folding and faulting of this area, the rocks are also highly fractured. Numerous fractures of various lengths cross the area; some of which may be faults. The fractures tend to be concentrated mainly in the Housatonic Highlands and Canaan Mountain areas which contain highly deformed rocks and relatively abundant bedrock outcrops.

3.5 Acquisition of Ground Truth Data

3.5.1 Standardization of Map Base

A photobase map scale of 1:250,000 was chosen to display geological information derived from ERTS-1 analysis. This scale was selected because of (a) its coincidence with the scale of existing geological maps (b) quality constraints which limit enlargement of ERTS imagery beyond this scale and (c) its compatibility with 1:250,000 USGS topographic sheets being utilized to graphically display snow depth information. Principal investigators, who are also utilizing New England as a test area, were contacted to promote information exchange. They generally concurred with use of a common (1:250,000) base map scale for information display.

3.5.2 Snow Information Network

3.5.2.1 Snow Depth Data Sources

In order to evaluate the effect of various depths of snow cover on fracture detectability, a ground reporting network was organized to periodically supply snow depth data. Various snow depth data acquisition methods were examined for applicability within the experiment including: (a) ground recording equipment (e.g., snow pillow recorders); (b) light aircraft snow points; (c) military weather stations; (d) National Weather Service Observers; (e) state supported weather stations; and (f) citizen volunteer work.

Ground recording equipment was unavailable for use in the experiment. Light aircraft snow points and snow depth information provided by military weather stations were utilized as required.

National Weather Service Observers located within the New England Test Area were the primary source of snow depth data. Volunteer observers were contacted using an explanatory experiment package to enlist their support. The package contained an introductory letter, experiment description, sample snow depth reporting postcard and a Reply Postcard to inform EarthSat of intent to participate in the experiment. Postcards provide a method which is inexpensive compared to the cost of a similarly scaled direct field effort. Participating observers were sent a follow-up letter, a list of the dates of ERTS overpasses for their area, and a supply of Snow Depth Reporting Postcards (APPENDIX E) for weekly reporting. Observation stations for postcard reporting were plotted on a 1:250,000 base map and isopach maps (Figure 8) were prepared from the reports and field observation data when available. The Massachusetts Department of Water Resources was requested to supply additional records.

To supplement low density reporting areas within both the New England and Maryland-Virginia Test Areas, area newspapers were requested to feature an article describing the ERTS program, the experiment and a request for public support. Reader response to EarthSat's article proved that significant public interest existed in the ERTS program. Readers who were selected as observers were supplied with Snow Depth Reporting Postcards.

The most frequent readings were reported during weeks of ERTS overflights. Snow depth data was collected weekly to establish melt or accumulation trends which may influence fracture detectability. It was hypothesized that maximum snow enhancement could be realized under conditions of differential melting, but this could not be fully evaluated from available ERTS data.

Field observations were undertaken by the investigators to increase the density of snow depth observations on selected dates. For example, nearly 100 snow depth readings were acquired for the New England Test Area in conjunction with the February 12 ERTS overpass. All snow depth reading were tabulated weekly on base maps. Snow isopach maps (Figure 8) were prepared using data from all sources in order to evaluate fracture detectability under varying conditions of snow cover. The results of these evaluations are discussed in section 5.3.3.

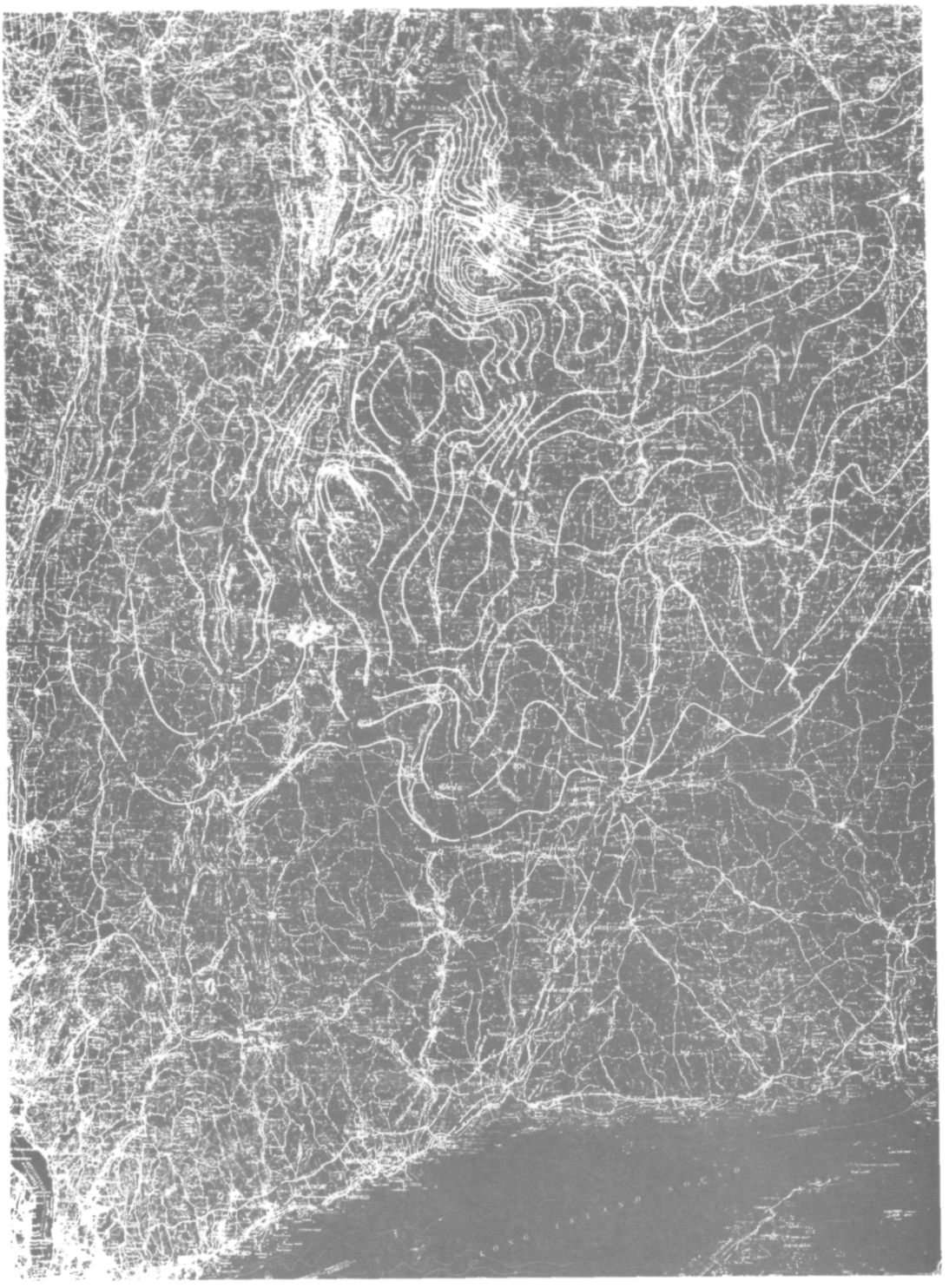


FIGURE 8: Snow depth isopach map of the New England Test Area for February 12, 1973. Snow depth isolines (one inch increments) were extrapolated from point measurements compiled from EarthSats Snow Depth Reporting Network and field measurements obtained directly by EarthSat scientists. Approximately 150 individual snow depth readings were used to construct this map. Isopach maps such as this one were routinely prepared for the dates of wintertime ERTS overpasses. These maps are used to evaluate the effect of varying snow depth on geological fracture detectability.

3.5.2.2 Accuracy of Snow Depth Maps

Observers were requested to obtain snow depth measurements at the same site throughout the experiment to minimize variables associated with selection of data acquisition sites. Observers were also requested to supply information concerning site location (e.g., hilltop, valley slope, valley bottom or plain) and extent of wind drifting. This information aided in the determination of a representative snow depth average for a given area. Since depth averages were utilized, variations in site measurement and associated errors were minimized.

3.5.3 Leaf Fall Data

A portion of the citizen reporting (ground data) network collected leaf fall information (e.g. percentage of leaf canopy) on the date of autumn ERTS overflights to more effectively analyze seasonal influences on fracture detectability.

Leaf fall data reported to EarthSat from New England observers was collected to aid in determining seasonal effects on fracture detectability and to determine a general date for leaf fall in the New England Test Area. Percentage of leaf canopy estimates were conducted on a weekly basis and coincident with the dates of ERTS over-flights at selected sites. By the October 22 ERTS overpass, less than 25% of the deciduous leaf canopy remained in the northern portion of the test area while the southern part of New England still retained an 85% canopy. The percentage of remaining leaf cover approached zero within the northern section of the test area by early November, while the same condition was not reported in the southern part until early December.

3.5.4 Geological Information Base

Various sources of geological information were available to spot check interpretive results. All 1:24,000 (7 1/2 minute) and 1:250,000 (1° x 2°) topographic maps of the New England and Maryland Test Area were acquired. Available geological quadrangle maps within the New England Test Area and state Geological Maps of Massachusetts, New Hampshire, Vermont, Connecticut and New York were obtained and analyzed. Major tectonic boundaries, lithological units, and structural trends were noted from this analysis. Geological map indices and geological reports for the New England Test Area supplemented existing map data.

Geological quadrangle, state geological maps and geological reports were used for the validation of lineaments interpreted from ERTS imagery and for testing the lithological discrimination capabilities of ERTS snow enhancement techniques. Topographic maps were used to eliminate lineaments interpreted from ERTS which were of cultural origin.

Only a small portion of an important source of current geological data was available to the investigators. The United States Geological Survey (USGS), was unable to provide the results of current mapping in the New England area; government policy provides that USGS cannot release unpublished geologic maps or reports unless first open-filed.

Field trips were made to the New England Test Area coincident with ERTS overflights to collect structural data. Preliminary field studies were conducted to assess the accessibility and density of outcrops, snow reference points, etc., (Figure 9). Special visits were made to key locations to field check lineaments observed from analysis of ERTS-1 imagery, collect snow depth readings and obtain structural joint readings. Fracture-lineaments derived from ERTS analysis were spot field checked to confirm their structural origin.

Within the test sites, a high density of bedrock joint readings were collected and compiled on the Fracture-Lineament map. Fracture directions were summarized on rose diagrams as a further indication of the structural validity of fracture-lineaments interpreted from ERTS imagery.

To broaden the scope of structural information within the New England Test Area, a geological lineament map was prepared from interpretation of Side Looking Airborne Radar (APS-94) imagery mosaics. This imagery was acquired in May-June, 1970 over the areas of Connecticut and Massachusetts in four separate look directions (N,S,E & W). Reproductions were acquired at a scale of 1:500,000.

3.5.5 Acquisition of Supporting Aircraft Data

The principal data source for this experiment was ERTS imagery; NASA aircraft data served as a validation tool and was used to clarify conditions of snow distribution, topographic relief, etc. Low altitude (4000 -5000 feet) vertical and oblique photographs from light aircraft were used to observe suspect lineaments, spot check SLAR-derived lineaments and observe snow cover variations (Figure 10).

FIGURE 9a: Large, nearly vertical joint (arrow) in a gneissic bedrock exposure along State Road 2 near Turners Falls, Massachusetts. Photograph was acquired in August, 1972 during field reconnaissance of geological lineaments (e.g., bedrock outcrops, joint systems). Joint measurements obtained in the field were subsequently utilized for constructing fracture rosettes to corroborate the structural validity of lineaments interpreted form ERTS analysis.

FIGURE 9b: Near-vertical joints (arrows) in exposed granitic bedrock along State Road 8A north of Plainfield, Massachusetts. The outcrop is about 10 feet in height. Photograph was acquired during February, 1973. Snow cover is approximately 8-10 inches and is thinnest in the area directly above the most prominent bedrock joint (large arrow). This condition is believed to have been caused by a higher melting rate in the joint zone.

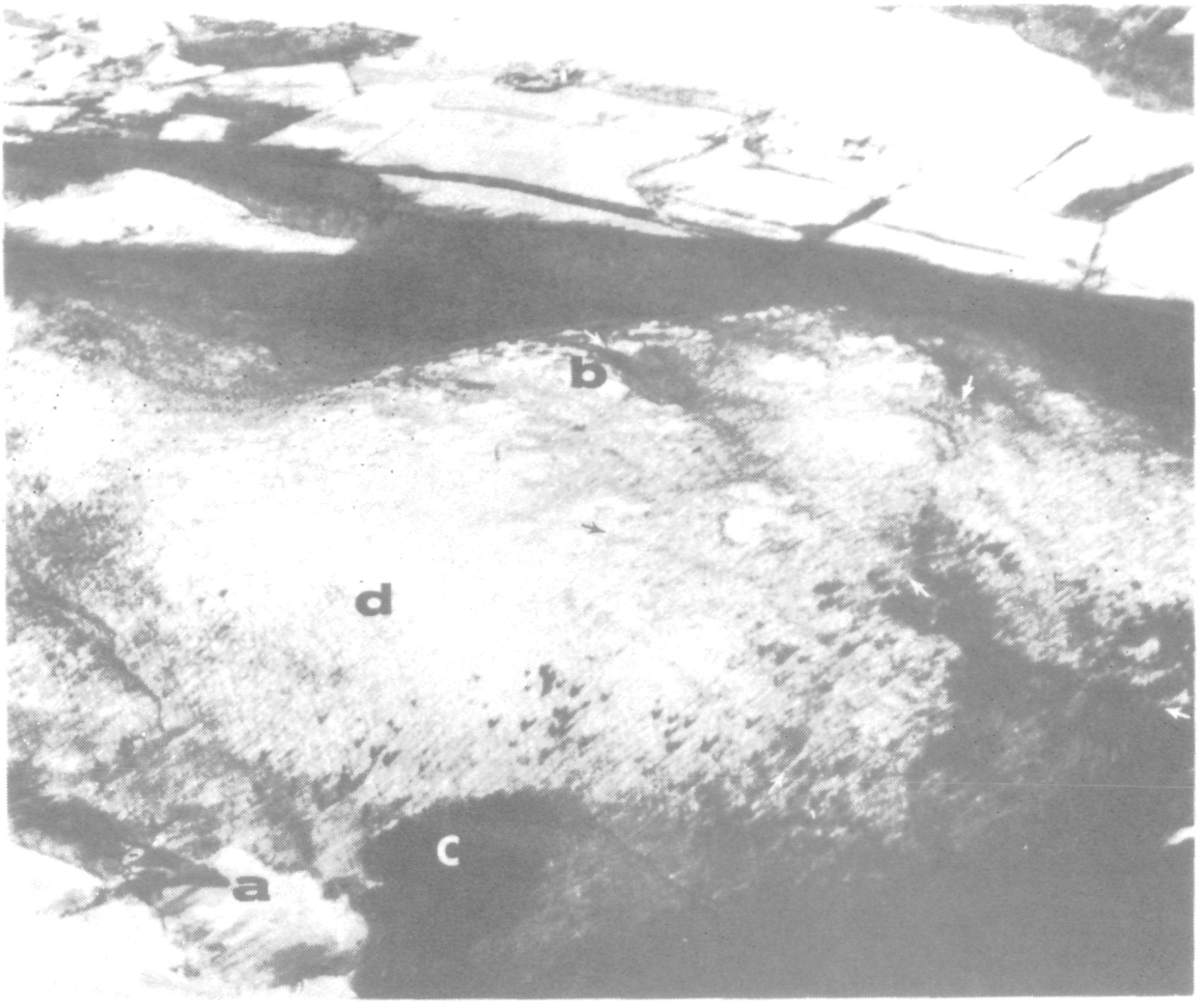


FIGURE 10: Aerial oblique photograph obtained from light aircraft over south-western Massachusetts along the New York border at an altitude of 4,000 feet on February 12, 1973. Snow cover is approximately 2-4 inches deep in the valley areas and 3-7 inches deep on the hillside. Cleared open fields and ponds (a) are rendered in very light tones. Light-toned, vegetation-free outcrops occur at the top of hill (b). Areas of coniferous cover (c) are rendered in dark tones; areas of deciduous tree cover (d) have slightly grayer tones. Differences in vegetative cover are accentuated by the increased surface contrast which a moderate cover of snow provides. Fractures (arrows) appear as moderately dark-toned lineaments due to topographic shadowing, differences in vegetation, and/or differential snow melt. The oblique imaging angle contributes further to the ease of detecting the fractures.

A light aircraft flight was made over the New England Test Area coincident with the February 12 ERTS-1 overpass.

Several high density fracture areas were observed from light aircraft; enhancement of fractures by snow cover was noted. Fracture detail as noted from aerial observation was greatest in snow covered areas of deciduous vegetation cover. Several coniferous vegetative alignments in fracture zones were also observed. Oblique photographs enhanced viewing perspective and, in the authors' judgment, proved more useful than near vertical photographs for lineament detection.

High altitude 1:120,000 scale color infrared (CIR) photography of the Great Barrington Test Site was acquired on January 31, 1973 by NASA U-2 aircraft. The photography was used to confirm the nature and origin of various geological features mapped using ERTS imagery. A number of subtle and generally shorter fractures were interpreted from the CIR photography but were not evident on the SLAR or ERTS imagery. The orientation of fractures mapped using the CIR photography correlated to a high degree with the ground truth data.

4.0 ERTS ANALYTICAL PROCEDURES AND TECHNIQUES

4.1 Visual Image Analysis

ERTS imagery was routinely received as both 9.5 inch prints and 70mm negative and positive transparencies. The prints were complemented by 1:250,000 scale enlargements made from 70mm transparencies. The enlargements served as a base for ERTS reconnaissance analysis and field operations. 9.5 inch positive transparencies were additionally ordered for ERTS scenes of high interest and/or quality.

4.2 Visual and Photographic Enhancement

The geological value of snow-cover and low angle solar illumination as natural enhancement for fracture analysis was confirmed in this investigation. Several additional viewing or processing techniques were found to increase the availability of lineament detail for the image analyst. An evaluation of the merits of the techniques that were tested follows:

4.2.1 Isodensity Processing

An ERTS-1 image of snow-covered terrain was selected for Agfacontour Isodensity processing. Colors indicative of various density levels were correlated with readings obtained from the snow depth reporting network. A general color-snow depth scheme to four levels of stratification was identified suggesting the utility for obtaining snow depth information. A source of surface snow depth data is required, however, to key various colors to actual snow depths. A problem in using isodensity processing is that ground spectral return is influenced by coniferous overstory which obscures snow cover. The reflectance of these areas and the resulting isodensity color rendition may not, therefore, accurately represent snow depth conditions. This difficulty may be partially overcome by extrapolating ground snow depth data and increasing the density of surface stations within areas of coniferous cover.

The isodensity process has value for enhancement of geological structure as a complement to manual analysis. Lineaments were generally enhanced by the differential snow cover which existed on this date (February 12) and were further enhanced through isodensity processing. Lineaments representing topographic alignments became especially prominent.

4.2.2 Ronchi Grating

The Ronchi grating is a refractive grating which has been reported to emphasize linear elements in an image. The use of a 200-line Ronchi grating for enhancing linear elements was evaluated

through visual and photographic analysis of ERTS data. Positive and negative transparencies of snow-free and snow-covered terrain within the New England Test Area were examined.

To photographically record the linear enhancement provided by the Ronchi grating, the grating was positioned between an illuminated transparency and a 35mm camera. The grating was then rotated slowly to identify "primary" and "secondary" lineament directions which were then photographed. Optimum enhancement occurs in accentuating linear elements with a high background contrast. Straight stream segments which appear in very dark tones on ERTS MSS Band 7 are accentuated against a background of light toned vegetative cover. (Figures 11 and 12).

The Ronchi effect appeared to "connect" what were really series of unconnected linear trends. This has some value for recognizing macro-trends of linear structural elements. Few lineaments which were previously undetected utilizing manual analysis procedures, however, were discovered through Ronchi enhancement.

In summary, the technique appears most effective for accentuating macro-trends, but made only a limited contribution to ERTS fracture analysis in snow covered terrain.

4.2.3 Film Sandwich

Film sandwiching involves the superposition of a black and white negative transparency upon its positive counterpart. Offsetting the transparencies in various directions accentuates linear features, and increases the ease with which they can be detected.

The double transparency sandwich may be used directly on a light table or as a negative for making prints. The effect of offsetting reduces all marked contrast and produces neutral gray over the entire frame. Textures are subdued while macro patterns (produced by varying textures and contrast) are lost. Bright lines are created along the contacts of high contrast areas to accentuate linear features with even limited relief.

For positive and negative transparencies of satisfactory density, both snow-free and snow-cover ERTS scenes were analyzed (Figures 13 and 14). Major linear trends and structural "grain," which correlated well with bedrock joint measurements recorded in the field, were accentuated by the snow-enhanced film sandwich. Geological trends were not as apparent on the snow-free image apparently because of the lower surficial contrast.

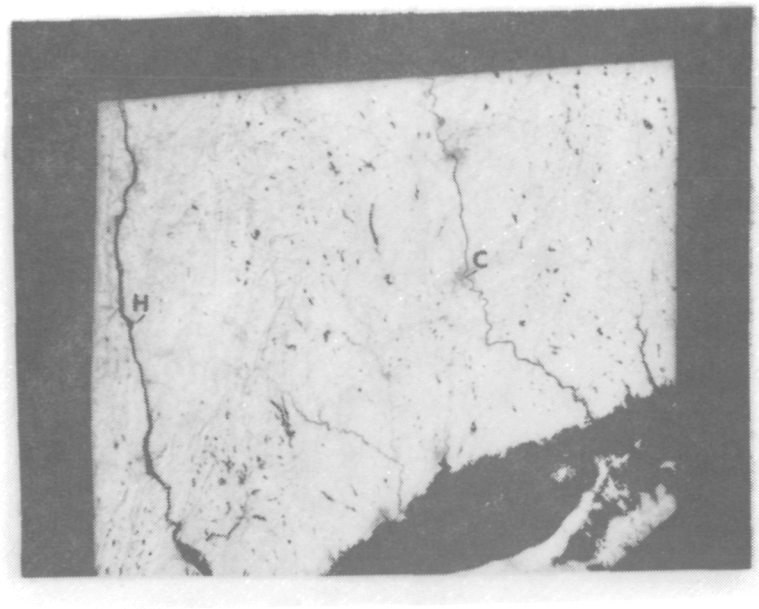


FIGURE 11: Snow-free ERTS image (1096-15072-7) acquired on October 27, 1972 over the New England Test Area. The Connecticut River (C) and the Hudson River (R) are identified as reference features.

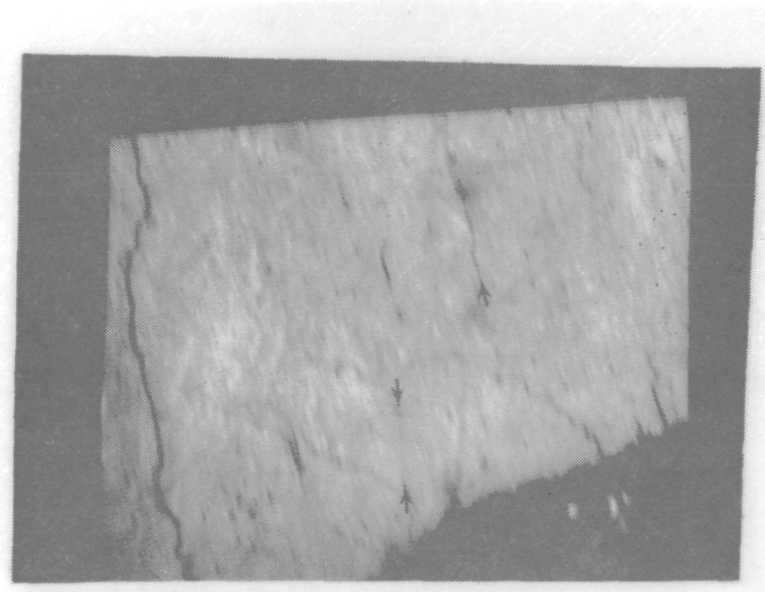


FIGURE 12: Snow-free ERTS image (1096-15072-7) photographed through a Ronchi Grating in an effort to preferentially enhance principal lineament directions. Straight stream segments and macro-linear trends (arrows) appear to have been accentuated. Micro-linear detail has been obscured to a large extent. Based on tests conducted within the New England Test Area, the Ronchi Grating technique is judged to have limited value for fracture mapping using ERTS imagery.

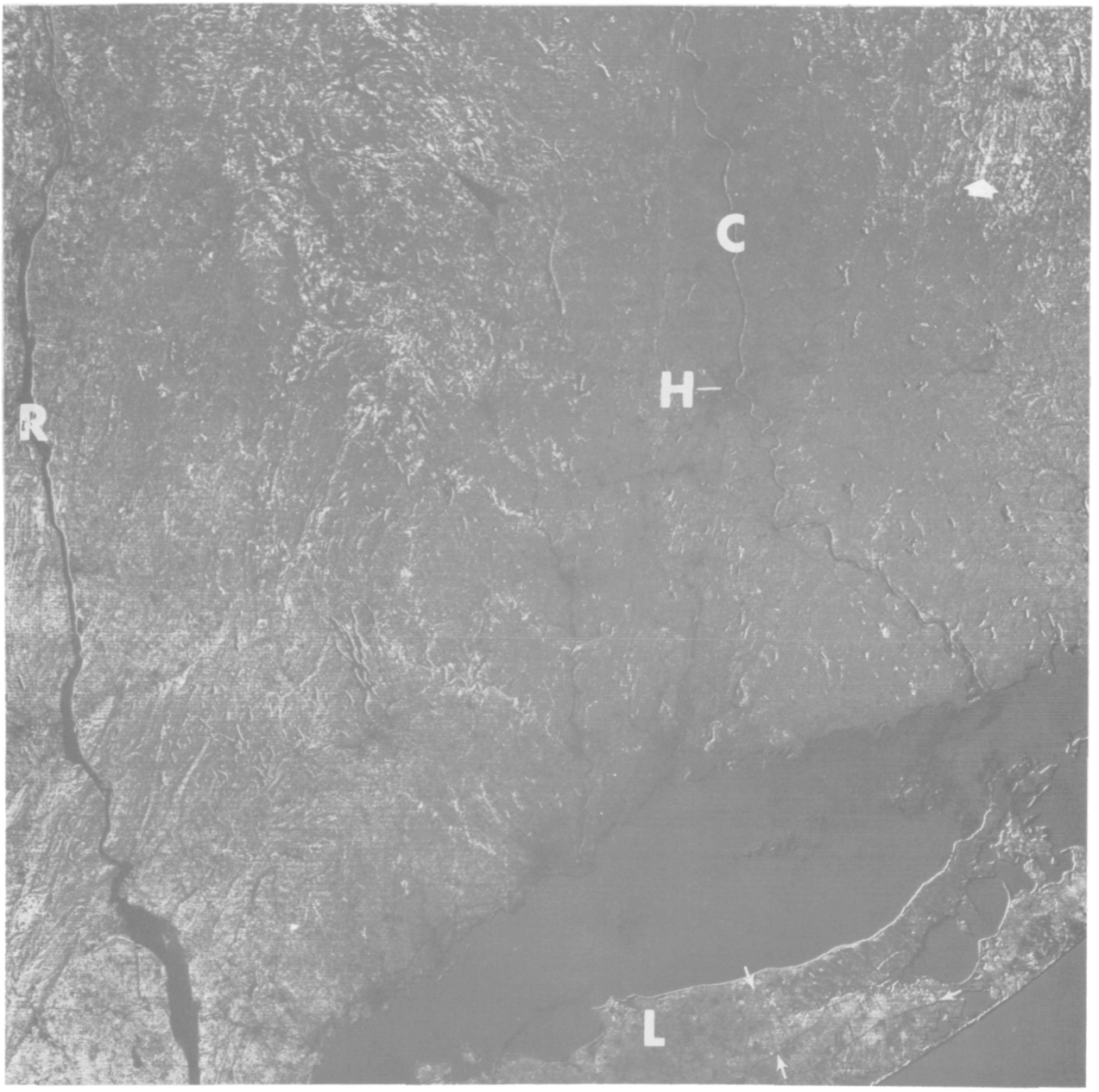


FIGURE 13: Photographic print of southern Massachusetts, Connecticut and Long Island (L) produced by "sandwiching" the positive and negative transparencies of an ERTS image (1096-15072-5) acquired on October 27, 1972. The transparencies have been slightly offset in approximately a north-south direction to emphasize linear features. The image is snow-free. Geographic reference features include the Hudson River (R), the Connecticut River (C) and the city of Hartford, Connecticut (H). Highways on Long Island are readily visible (small white arrows). Geological trends in the western half of the image (black arrow) were judged from comparative analyses to be less obvious than on the snow-cover sandwich on the following page. A N-S grain in the eastern half of the image may be seen (large white arrow). This corresponds to the principal direction of bedrock foliation in this area.

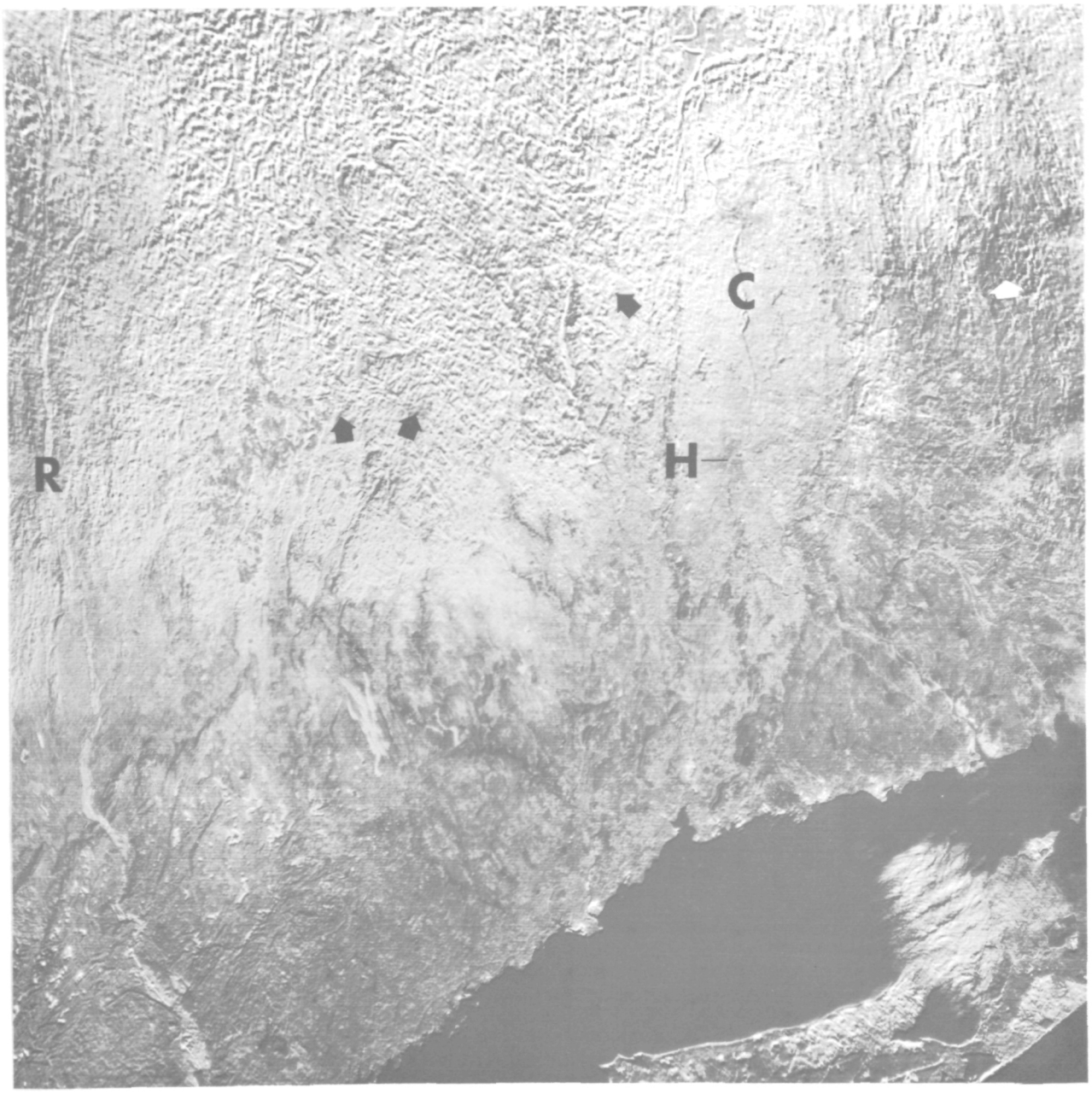


FIGURE 14: Photographic print of southern Massachusetts, Connecticut and eastern Long Island made from the "sandwiching" of the positive and negative transparencies of an ERTS image (1204-15074-5) acquired on 12 February 1973. The transparencies have been slightly offset (in approximately a north-south direction) to emphasize linear features. The upper half of the image is snow-covered. Geographic reference features include the Hudson River (R), the Connecticut River (C) and the city of Hartford, Connecticut (H). Major linear trends and structural "grain" are accentuated by the sandwich. Three major structural trends (black arrows) are noticeable in the western half of the image. The trends correlate well with bedrock joint measurements recorded in the field. The correlation apparently confirms the structural nature of the enhanced lineaments. The N-S grain in the eastern half of the image (white arrow) corresponds to the general trend of bedrock foliation.

The film sandwich is a low-cost form of edge enhancement which can serve many user groups. The film sandwich is at least as effective as optical edge enhancement techniques tested within this experiment for fracture analysis in snow-covered terrains.

4.3 Optical Enhancement

4.3.1 Density Slicing

Density slicing techniques were tested for discriminating varying depths of snow cover. An I²S digicol was used to convert gray level differences in black-and-white ERTS imagery into as many as 32 separate colors on a television monitor. ERTS imagery of snow-covered terrain within the New England Test Area was used; various color combinations and gain settings were tested. Density slicing discriminations were compared with a snow depth map compiled from data supplied by the snow depth reporting system.

A minimum of three snow-cover categories were reliably attainable utilizing density slicing. They were (a) snow-free, (b) < 1 inch, and (c) > 1 inch. Additional categories (i.e., 1-4 inches and >4 inches) could sometimes be discriminated under certain conditions, e.g., where terrain was predominately covered with low growth vegetation such as grassland or meadow and land use was not mixed. Extrapolating snow depth information from open areas into or through large areas of coniferous tree cover proved difficult.

4.3.2 Additive Color Viewing

ERTS-1 images of snow-covered and snow-free terrain were combined utilizing additive color combinations of MSS bands 4, 5 and 7 on an I²S addcol. This system allows the projection and combination of as many as four separate black-and-white images acquired in different spectral bands. Various filters may be utilized and intensity levels varied to produce a wide range of additive color renditions. The investigators found that additive color procedures could furnish new lineament information (e.g., accentuation of vegetative alignments related to fracture control). Blue-Green-Red and Red-Blue-Red filter combinations proved best for lineament discrimination.

Offsetting or misregistration of positive images provided no new fracture information. In some cases, negative transparencies enhanced snow-covered lineaments of cultural origin, (e.g., light-toned transmission line right-of-way). Negative transparencies, utilizing clear and blue filter combinations, generally enhanced topographic relief as a function of shadowing. Vegetative alignments were more conspicuously rendered utilizing standard filter-band

assignments (i.e., MSS bands 4, 5 and 7 combined with blue, green and red filters respectively) and positive transparencies.

4.4 Automated (Digital) Analysis

An effort was made to use digital processing data to enhance structural lineaments. Images with computer enhanced edge detail were produced from MSS data (Figure 15). Although computer enhancement sharpened the image, the investigators found no appreciable increase in geological fracture detail.

As a complement to manual analysis, attention was also directed toward the automated generation of rose diagrams, i.e., polar plots characterizing the orientation of linear trends within a scene. Due to the significance of such an automated rose diagram technique for geological interpretation, EarthSat has funded and continues to fund research in the area. Three proprietary programs have been evaluated for relevance to this project:

a) IPSYS, an interactive image processing software system developed jointly by EarthSat and IBM

b) ROSE, a batch mode Fortran program specifically designed for rose diagram generation employing 4 pixel gradient determination

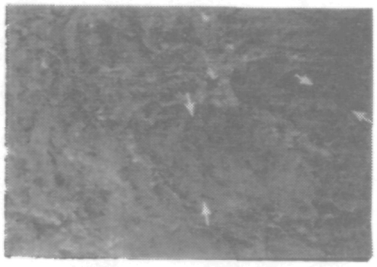
c) ROSE 2, also a batch mode Fortran program, a major modification of ROSE, employing 25 pixel gradient determination.

Each of these has been applied to ERTS imagery and the results have been compared with a manually generated rose diagram. No satisfactory agreement has as yet been found, however further research is underway.

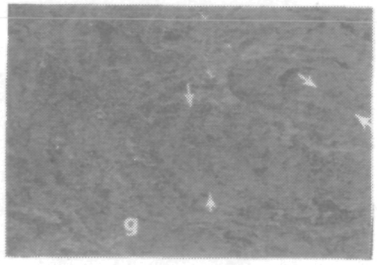
The problem has proven as difficult as was anticipated during the early stages of the investigation. Specifying an algorithm that emulates the perceptions of the trained photo geologist and discriminates between the meaningful and irrelevant linear features has yet to be satisfactorily accomplished.

4.5 Fracture-Lineament Validation

A fracture-lineament validation system was designed to further strengthen differentiation between geological lineaments and cultural linears in areas of sporadically exposed bedrock (New England Test Area). The system centers on the analytical results of trained photogeologists, complemented by topographic maps, geological maps, radar lineament maps (prepared independently in this experiment) and bedrock joint readings



A



B

FIGURE 15: ERTS-1 image (1096-15072-5) of a portion of the Great Barrington, Massachusetts Test Site acquired on October 27, 1972. The imaged area contains approximately 225 sq. miles. The town of Great Barrington (g) is identified as a geographic reference. Image A is the original image. Image B is an example of spatial computer enhancement (Laplacian of image added to original). Digital enhancement did not yield a significant increase in fracture detail although the image was slightly clearer. Difficulties encountered in processing precluded testing with snow-covered imagery. A sampling of fracture-lineaments (arrows) is shown.

obtained in the field. The system is designed to add (or subtract) successive "weight" to an image lineament interpreted from ERTS by checking its coincidence with existing data (Figure 16). For operational mapping using snow enhancement interpretation techniques, this validation procedure can be expanded or condensed depending on such factors as the availability of supporting information or program budget.

Image lineaments which met validation criteria were recorded as fracture-lineaments on the ERTS photo base map for western Massachusetts. The investigators recognize the importance of confirming the structural origin of lineaments mapped from analysis of ERTS imagery by field observation as contrasted with the mapping of image-lineaments as an end in itself. The sequential validation system was designed in lieu of final validation, i.e., field analysis for area wide geological fracture mapping and analysis.

The validation procedure was applied intensively to detailed test sites, and more generally for validating linear features on the Fracture-Lineament Reconnaissance Map of western Massachusetts.

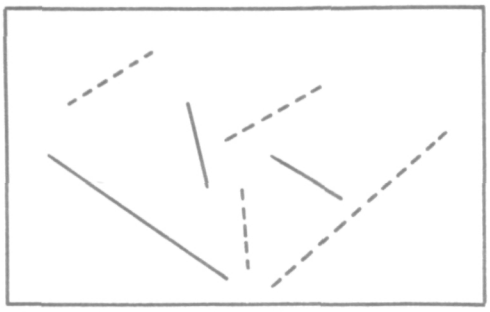
The validation steps which were used in this investigation are the following:

4.5.1 Multi-Interpreter Analysis

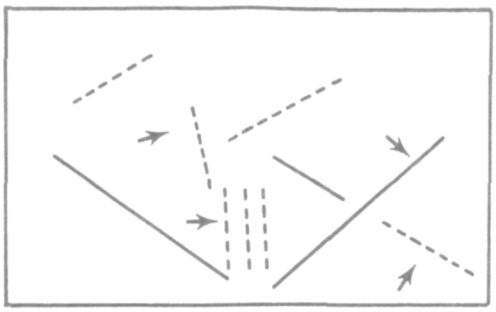
All ERTS imagery was analyzed as received by succeeding image analysts in a three-interpreter sequence. Prints at 1:1,000,000 scale were analyzed by each interpreter who also had access to ERTS transparencies. Equal attention was given to all ERTS bands - whether snow-covered or snow-free - during preparation of the Fracture-Lineament Reconnaissance Map; increasing dependence was placed upon snow-enhanced Bands 5 and 7 images during detailed test site studies. An image-lineament identified by three interpreters was designated with a solid line; where only one or two identified it, it was designated by a dashed line.

4.5.2 Topographic Map Comparison

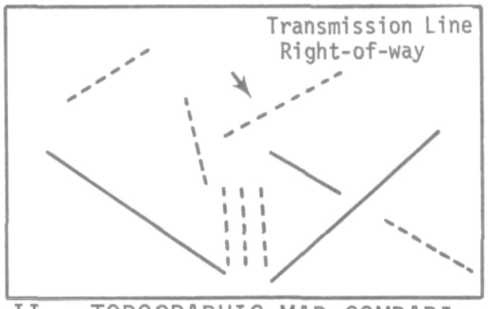
1:250,000 scale topographic maps were used to check lineaments against topographic features to eliminate all major cultural linear features. Some reduction in cultural linears occurred directly from analysis of snow-enhanced imagery, e.g., identification of transmission line right-of-ways. As anticipated, image lineaments coincided with mapped cultural features such as highways. In these cases special effort(such as additional field checking, examination of 7.5 minute topographic maps, etc.) was directed to confirming the origin of the lineament. Linear features which coincided with cultural features and which lacked any evidence of geological structure were deleted.



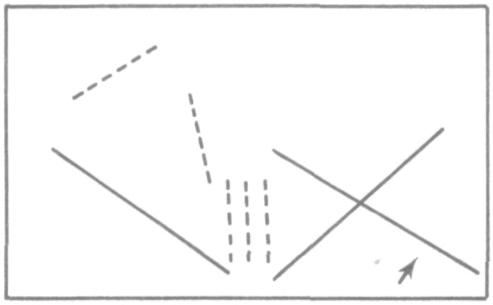
Ia. ERTS IMAGE ANALYSIS
(initial analyst)



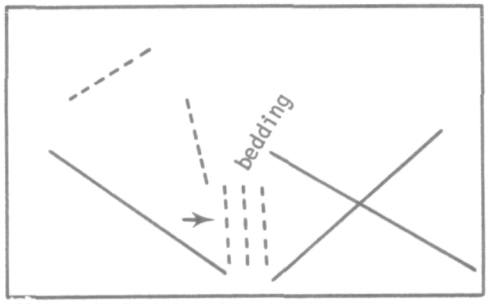
Ib. ERTS IMAGE ANALYSIS
(succeeding analysts)



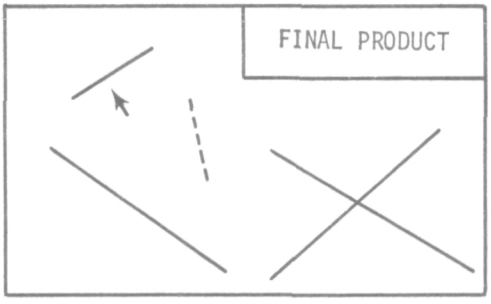
II. TOPOGRAPHIC MAP COMPARISON



III. RADAR LINEAMENT MAP COMPARISON



IV. GEOLOGICAL/GEOPHYSICAL 1/ MAP COMPARISON



V. FIELD VERIFICATION
(bedrock joint measurements and observations)

——————— Fracture-lineament confimed by sequential validation system
---------- Fracture-lineament unconfirmed by sequential validation system
➔ Indicates a change in status (upgrading, downgrading, addition or deletion) of fracture-lineament

FIGURE 16: Illustration of the sequence used for fracture-lineament validation. All linear features mapped from analysis of snow-enhanced and snow free imagery were examined using a system of upgrading or downgrading based on: consecutive image analysis by three photogeologists, topographic maps, geological maps, glacial maps, aeromagnetic maps, radar maps and selective field observation. Geological features such as bedding, foliation, thrust faults, and normal faults identified from collateral sources were not mapped.

1/ Includes aeromagnetic, glacial, surficial and/or bedrock quadrangle maps.

4.5.3 Radar-Lineament Map Comparison

Radar-lineaments mapped from analysis of 1:250,000 scale SLAR mosaics 1/ of the New England area were utilized for validation as follows: (a) where the radar-lineament corresponded to an image lineament (solid line), no change was made; dashed (image lineament) lines, however, were upgraded to solid lines, (b) where radar-lineaments appeared particularly strong and did not correspond to identified ERTS-1 lineaments, ERTS imagery was double-checked using validation step 1.

4.5.4 Geological/Geophysical Map Comparison

All published data on available geological maps of the area were reviewed. 2/ Because of the active mapping program in the area, a special effort was made to gather new information rather than simply confirm existing data which were quite limited in quantity. Geophysical (aeromagnetic) data were used to confirm interpretive judgments and eliminate lineaments which were manifestations of bedding or foliation. Foliation could usually be differentiated from fracture-lineaments because of its closely spaced characteristic sinuous to curvilinear patterns and its north to northeastern trends. The aeromagnetic data were used to eliminate non-fracture information; lineaments were not upgraded or downgraded (i.e., solid line to dashed) based upon this information.

Glacial maps (Figure 17) were also consulted to determine if image lineaments conformed with major directions of glacial advance. Field observation confirmed that many lineaments coincided with glacially enhanced bedrock fractures; glacial scour along preferred joints increased fracture relief and therefore the detectability of fracture-lineaments. ERTS lineaments which tended to coincide with glacial striations were generally field checked to confirm their structural validity.

4.5.5 Field Observation

Field observations throughout the area generally involved three distinct steps:

(a) Locate outcrops in the general vicinity of mapped lineaments, and make joint readings to check correspondence of joint directions with ERTS-derived lineaments.

1/ All four look directions were used as possible.

2/ USGS mapping is in progress in the area, but preliminary field maps were generally unavailable for purposes of the study. Geological quadrangle mapping in the next several years may benefit from data developed in this experiment.

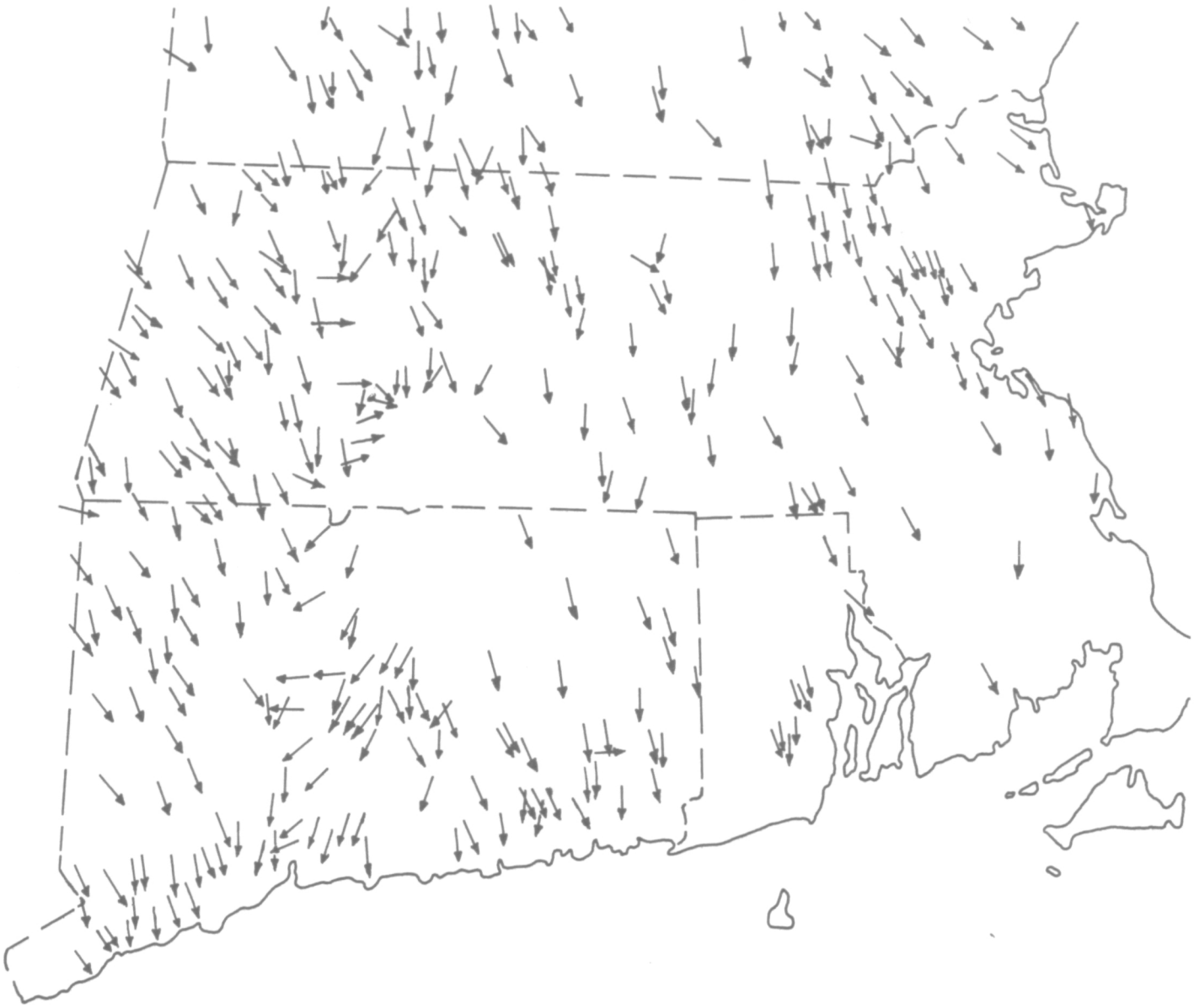


FIGURE 17: Glacial striation directions within southern New England recorded from direct field observations. These striations are utilized by the investigators to cross check the structural validity of fracture-lineaments interpreted from ERTS imagery (Modified after Flint, 1967).

(b) Observe topographic relationships such as straight stream segments, regional linear depressions, etc. Many of the structural features on existing maps of the area are necessarily extended - because of limited outcrop data - through areas of generally negative relief.

(c) Make observations for evidence of faulting and fault zone mineralization.

The field observation programs conducted in this investigation can undoubtedly be continued for many years to further strengthen the geological validity of the mapped fracture lineaments.

4.5.6 Aircraft Observations

Light aircraft observations of selected lineaments were conducted to complement field studies. Available NASA U-2 aircraft imagery was also used. Particular emphasis was given to sites where satisfactory perspective could not be obtained in the field. This step was utilized as required to supplement the information derived in the preceding five steps.

5.0 INVESTIGATION RESULTS

5.1 Utility of ERTS MSS Bands

ERTS MSS Bands 4 (500-600nm), 5 (600-700nm), 6(700-800nm) and 7 (800-1100nm) of the New England Test Area were intensively analyzed throughout the study. Comparative analyses repeatedly demonstrated that MSS Bands 5 and 7 supply the greatest amount of fracture data for snow free terrain (Table 2). The detectability of various geo-environmental data using snow enhanced ERTS MSS imagery was also assessed (Table 3).

MSS Band 4 proved to have the lowest utility of the four bands for acquisition of geological data. MSS Band 5 provided the greatest tonal contrast and had the greatest applicability for fracture mapping in both snow-free and snow-covered terrains. Band 7 provided an effective complement to Band 5 for fracture analysis; Band 6 did not provide as great a quantity of fracture information as Band 7.

ERTS-1 color composites (1204 - 15074 and 1204 - 15072) of snow covered terrain were analyzed to evaluate their utility for fracture mapping. Several image lineaments, not detected using single-band manual and enhanced manual analysis techniques, were identified using ERTS color composites. The combined factors of differential snow-cover, color rendition, and low sun angle resulted in an increase in lineament detectability. Fracture-influenced vegetative alignments were best observed utilizing snow-covered ERTS color composites. In direct contrast, color composite ERTS images (1096-15065 and 1096-15072) of snow-free terrain of the same area provided less fracture data than black-and-white snow-free images acquired on the same date. This was attributed to a lack of tonal contrast in the composite image which was rendered in red hues due to the predominance of forest cover.

5.2 Seasonal Factors and Fracture Detectability

A general analysis of the influence of seasonal variations on fracture detectability was conducted. Imagery for all four seasons was compared for ease of fracture detection and quantity of fracture data acquired. The summer imagery provided the least fracture-lineament detail. Snow covered wintertime imagery provided the most fracture-lineament information while autumn imagery (after leaf fall) ranked second in information yield. Comparisons between 1972 and 1973 ERTS imagery revealed that the trend of leaf fall was regionally detectable based on reflectance characteristics best seen on MSS Band 7. The trends of leaf fall

TABLE 2: EVALUATION OF FRACTURE DETECTABILITY UTILIZING MULTISPECTRAL ERTS-1 IMAGERY OF SNOW-COVERED TERRAIN

FRACTURE-LINEAMENT INDICATORS	MSS BANDS[1]				
	BAND 4	BAND 5	Band 6	Band 7	Color Composite[2]
DIFFERENTIAL SNOW COVER PATTERNS	poor	excellent	fair	fair	good
TOPOGRAPHIC SHADOWING	poor	good	good	excellent	good
WATER BODY ALIGNMENT (Straight Stream Segment, etc.)	poor	fair	good	excellent	good
VEGETATIVE ALIGNMENTS	fair	good	poor	poor	excellent

[1] Band 4 (500-600nm.), Band 5 (600-700nm.), Band 6 (700-800nm.) Band 7 (800-1100nm.)

[2] Color composites combine the advantages of using both MSS Bands 5 and 7, but with some loss in resolution, introduction of background "noise" and increased cost.

TABLE 3: DETECTABILITY OF GEOLOGICAL AND GEO-ENVIRONMENTAL DATA UTILIZING SNOW ENHANCED ERTS IMAGERY

GEOLOGICAL/GEO-ENVIRONMENTAL FEATURES	MSS BANDS				
	BAND 4	BAND 5	BAND 6	BAND 7	COLOR COMPOSITE
FRACTURE-LINEAMENTS	5	1	4	2	2
STRATIGRAPHIC LINEAMENTS	3	2	4	5	1
CULTURAL LINEARS (Transmission Lines, Airport Runways, etc.)	3	1	4	5	2
SNOW DEPTH ESTIMATION	1[1/]	4	5	1[1/]	3
VEGETATIVE COVER	3	2	4	5	1
OUTFALLS[2/]	2	1	4	5	3
LAND USE DIFFERENCES	5	2	3	4	1

NOTE: The number one (1) identifies the best band for detection and analysis of the given feature.

[1/] The two bands can be utilized to supply complementary snow depth information, particularly for discrimination of melting snow cover.

[2/] Outfalls which are manifested as unfrozen areas within water bodies with a predominantly frozen surface.

between the two dates were found to be closely parallel. This information substantiated that the best available (trees were leaf free) snow-free image (1096-15072, Oct. 27) was utilized in the fracture detectability test described below. An illustration of the comparative detectability of ERTS fracture-lineaments for spring, fall and winter is included (Figure 18).

A comparative analysis test was conducted to quantitatively assess the relative detectability of image lineaments interpreted from imagery of snow-free versus snow-covered terrain. Two photogeologists, unfamiliar with ERTS imagery of the New England Test Area, were each requested to conduct a geological analysis utilizing four ERTS frames. One set of images was snow-free and acquired after leaf fall (1096-15065 and 1096-15072); the other set was snow-covered (1204-15072 and 1204-15074). All images were judged to be of comparable photometric quality.

Band 5 imagery was selected because it had been previously judged at least as good as Band 7 and better suited than Bands 4 and 6 for fracture analysis. The analysis area on images 1096-15072 and 1204-15074, which both contained the same segment of the test area, were made to coincide with the lower limits of snow cover on image 1204-15074.1/ This was undertaken to exclude any snow-free areas from the principally snow-covered image. Additionally, a cloud-covered area was masked out on image 1204-15072 and the equivalent snow-free image of the same area (1096-15065) so that the available area for the fracture analysis would be identical on both images.

Each analyst was instructed to map lineaments on clear acetate overlays for a total of 30 minutes per frame. In an attempt to compensate for memory bias, Analyst A was instructed to begin on the snow-free imagery, Analyst B began on the snow-covered imagery. Analysts allowed about a week to elapse between analysis of snow-free and snow-cover imagery. The analysts were instructed to map lineaments no shorter than 1/4 inch (approximately 4 miles on the ground) to eliminate unnecessary detail and to minimize the possibility of mapping lineaments caused by system "noise," or emulsion scratches.

1/ Only the northern and middle portions of the test area were utilized for the comparative test since snow cover did not occur in the southern portion.

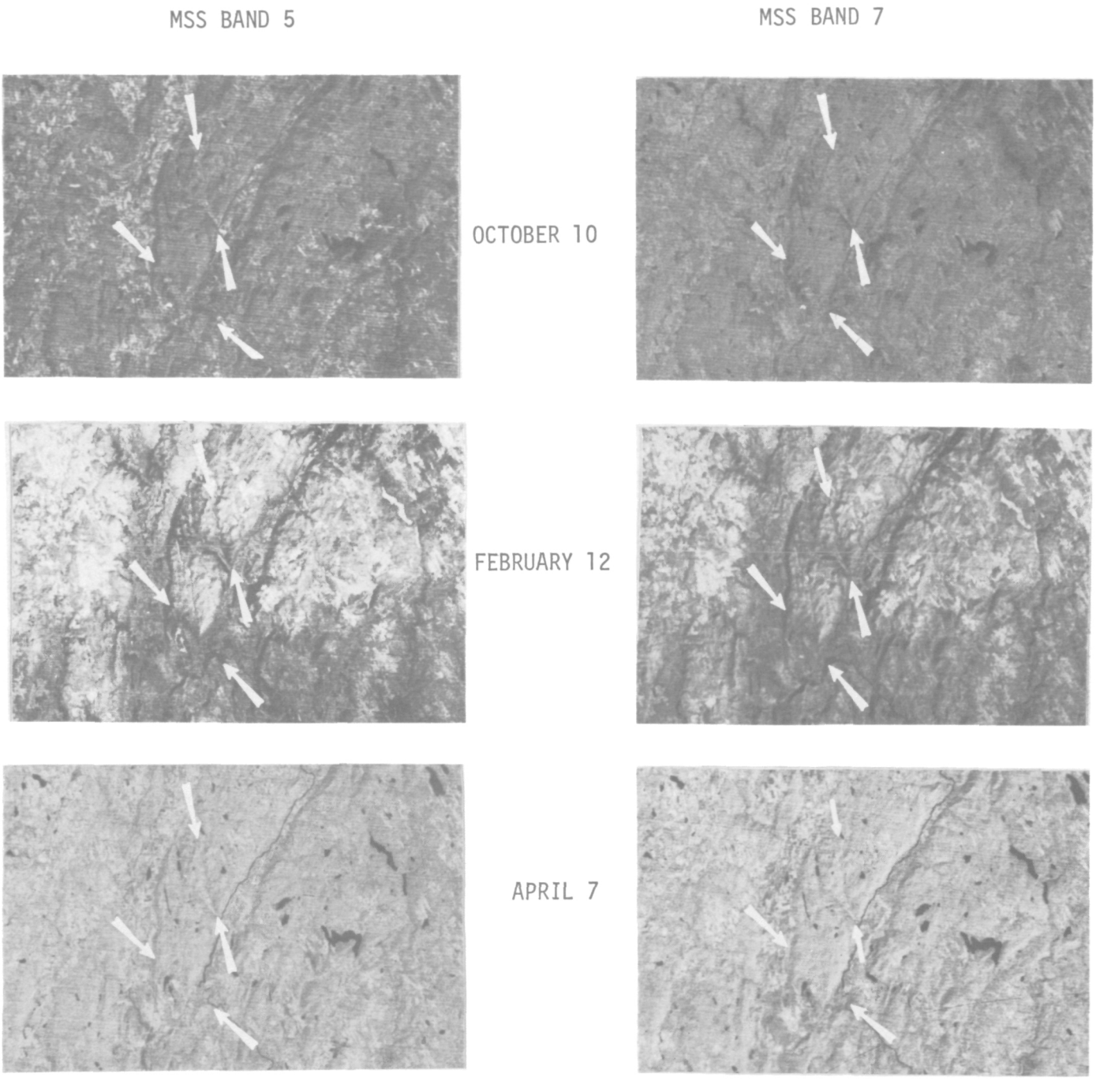


FIGURE 18: ERTS-1 imagery enlarged to a scale of 1:500,000 and acquired with MSS Bands 5 and 7 over the New York - Connecticut border. Macedonia Brook State Park is located near the center of the image area. The images demonstrate the influence of seasonal changes on fracture detectability. The February image contains a moderate snow cover (1-4 inches). The October and April images are snow free. Greater fracture detail was obtained from the snow-covered imagery during comparative analysis tests. This was attributed to the greater tonal contrast which a differential cover of snow provides. Several prominent fracture-lineaments (arrows) are indicated on the images. These features are difficult to detect on the snow-free images, particularly the April 7 imagery.

To establish the relative quantity of potentially usable geological data obtained from ERTS imagery, the total length and the total number of all image lineaments were recorded. The results are summarized in Table 4. It was observed that in three out of four instances, more lineament detail was mapped on the snow-covered than on the comparable snow-free imagery. The fracture information acquired included not only a larger number of interpreted lineaments, but also a greater total length of all the lineaments mapped on this imagery. The photoanalysts attributed the increased lineament detectability with snow cover to the greater tonal contrasts which the surficial snow cover provided.

5.3 Geological Utility of Snow Enhancement Techniques: Fracture Enhancement

5.3.1 General

Based on analytical tests, detection and analysis of geological fracture systems can be more effectively conducted utilizing snow cover as an enhancement tool. Field and light aircraft observations provided insight as to why fracture systems are enhanced by snow cover. Vegetative differences, including vegetative alignments, often contributed to the observed tonal differences between fractures and surrounding terrain. Fracturing was comparatively difficult to detect in areas of dense coniferous tree cover; snow cover accentuated fractures even in dense deciduous stands. With leaf cover fracture detection would have been difficult in such areas.

The enhancement effects of snow cover may be broadly categorized as differential permeability (thermal variations), topographic shadowing, vegetative alignments, or some combination of such phenomena (Table 5). The apparent absence of snow cover can most often be attributed to accelerated melting rates induced by the higher moisture content within fracture zones, or the obscuration of snow cover by vegetative overstory.

Based on field observations, new snowfall patterns or differential snow melt patterns within unfrozen materials are often diagnostic of variations in the moisture content (and thermal properties) of surface and subsurface materials (Figure 19). Soils with a high moisture content were the last areas to permit snow accumulation in new snowfalls. Similarly, these areas were the first to lose snow cover during periods of melt. This situation is attributed to the higher heat capacity of areas with a high moisture content. Fracture zones were observed to have a higher moisture content than surrounding areas.

TABLE 4: COMPARATIVE ERTS ANALYSIS TEST:

SNOW FREE VS. SNOW ENHANCED IMAGERY

Analyst A

Total Interpreted Image Lineaments	Comparative Set #1		Comparative Set #2	
	1096-15065 (SNOW FREE)	1204-15072 (SNOW COVER)	1096-15072 (SNOW FREE)	1204-15074 (SNOW COVER)
Number	287	312	336	267
Length(cm)	213	287	327	331

Analyst B

Total Interpreted Image Lineaments	Comparative Set #3		Comparative Set #4	
	1096-15065 (SNOW FREE)	1204-15072 (SNOW COVER	1096-15072 (SNOW FREE)	1204-15074 (SNOW COVER)
Number	137	175	167	216
Length(cm)	105	131	152	197

TABLE 5: ENHANCEMENT CAPABILITIES OF SNOW COVER

(Determined from Analysis of ERTS-1 and ERTS Underflight Imagery)

PHENOMENA CATEGORY[1/]	RATIONALE	ENHANCEMENT/INFORMATION
SNOW DUSTING (differential accumulation)	A light wind-swept snow cover enhances subtle topographic variations; snow may be swept from ridges to valley, drifts and accumulates in the lee of vegetative alignments, etc. Shadows indicating topographic expression are accentuated against the background of snow cover.	Enhanced Topography-Augmented Resolution-Increased Tonal Contrast from shadowing on snow.
SNOW MELT PATTERNS (differential melting)	Differential melt patterns are related to texture/ permeability differences in subsurface materials which can be indicative of fracture zones.	Augmented Resolution-Increased Tonal Contrast
VEGETAL SNOW MASKING	Differences in plant density, height and over-story obscure snow cover to varying degrees. Vegetative alignments frequently signal differences in substrata texture/permeability which may be indicative of fracture zones.	Increased Tonal Contrast (between boundaries of vegetative cover types). Enhancement based on differences in vegetation density and type.
DYNAMIC SNOW COVER PATTERNS	Monitoring changes in snow cover may yield information related to changing surface or sub-surface conditions (e.g. rising of ground water table) which may influence the moisture content and therefore the heat capacity of fracture zones.	Increased Tonal Contrast - Relative Thermal Condition of Ground Materials

1/ The boundaries between the individual phenomena categories are sometimes difficult to define, i.e., various phenomena act in combination (rather than alone) to provide geological data.

FIGURE 19a: Enhancement of transmission line right-of-way by snow cover (View north from Quabbin Reservoir, Massachusetts). Transmission line and pipeline right-of-ways are generally visible as white linear features against a darker background of vegetative cover. In snow-covered terrain fracture traces are generally seen as dark lines of snow melt, topographic shadowing or vegetative alignments.

FIGURE 19b: Bedding planes (arrows) of moderately dipping (30-35° south) slaty bedrock enhanced by differential snow cover. Without snow cover these planes would not be as prominent due to the dark color of the bedrock, soil cover and/or the presence of fallen leaves. This illustration indicates the potential value of snow cover for geological field reconnaissance. Photograph acquired on State Road 8 near Adams, Massachusetts on February 11, 1973.

5.3.2 Low Sun Angle

Image analysts have long recognized that topographic changes can be detected when sun-facing slopes are illuminated and back slopes are in darkness. This situation is analogous to side-looking airborne radar (SLAR) imagery 1/ flown parallel to structural trends. Slopes facing the aircraft give strong (bright) returns while far slopes produce a black radar shadow (Figure 20).

When slopes are snow covered, low angle solar illumination contributes to discrimination of topographically-expressed structural lineaments. Without the use of snow enhancement, low angle solar illumination will not generally permit visual detection of subtle linear or textural features (including faults in glaciated terrain) from low resolution imagery.

Snow cover when combined with low angle solar illumination, aids in the detection of subtle fractures with subdued surface expression by increasing the tonal (shadow) contrast of the topographically shadowed or vegetatively enhanced lineament against a uniform illuminated snow-covered background. Snow melting is also accelerated in the moist zones within and above fracture zones and images as dark tones. In many areas, vegetative alignments enhanced by snow cover permitted fracture-lineament detection using ERTS-I imagery.

5.3.3 Effects of Snow Depth on Fracture Analysis

Based on ERTS image analysis and complementary snow depth observations, a light to medium cover (1-4 inches) is the optimum depth for snow enhancement. This range was confirmed from comparative analysis conducted on ERTS wintertime scenes of three different dates (December 2, January 7 and February 12). Fracture detail for each scene was then compared with snow depths contained on isopach maps.

1/ Snow-enhanced ERTS imagery resembles SLAR imagery. ERTS imagery of snow-covered terrain without supporting aircraft coverage complements SLAR imagery by providing fracture-lineament data in areas of relatively deep soil and subdued topography where SLAR is not as effective. It is important to note that SLAR does not replace the geological data yield of snow-enhanced ERTS imagery.

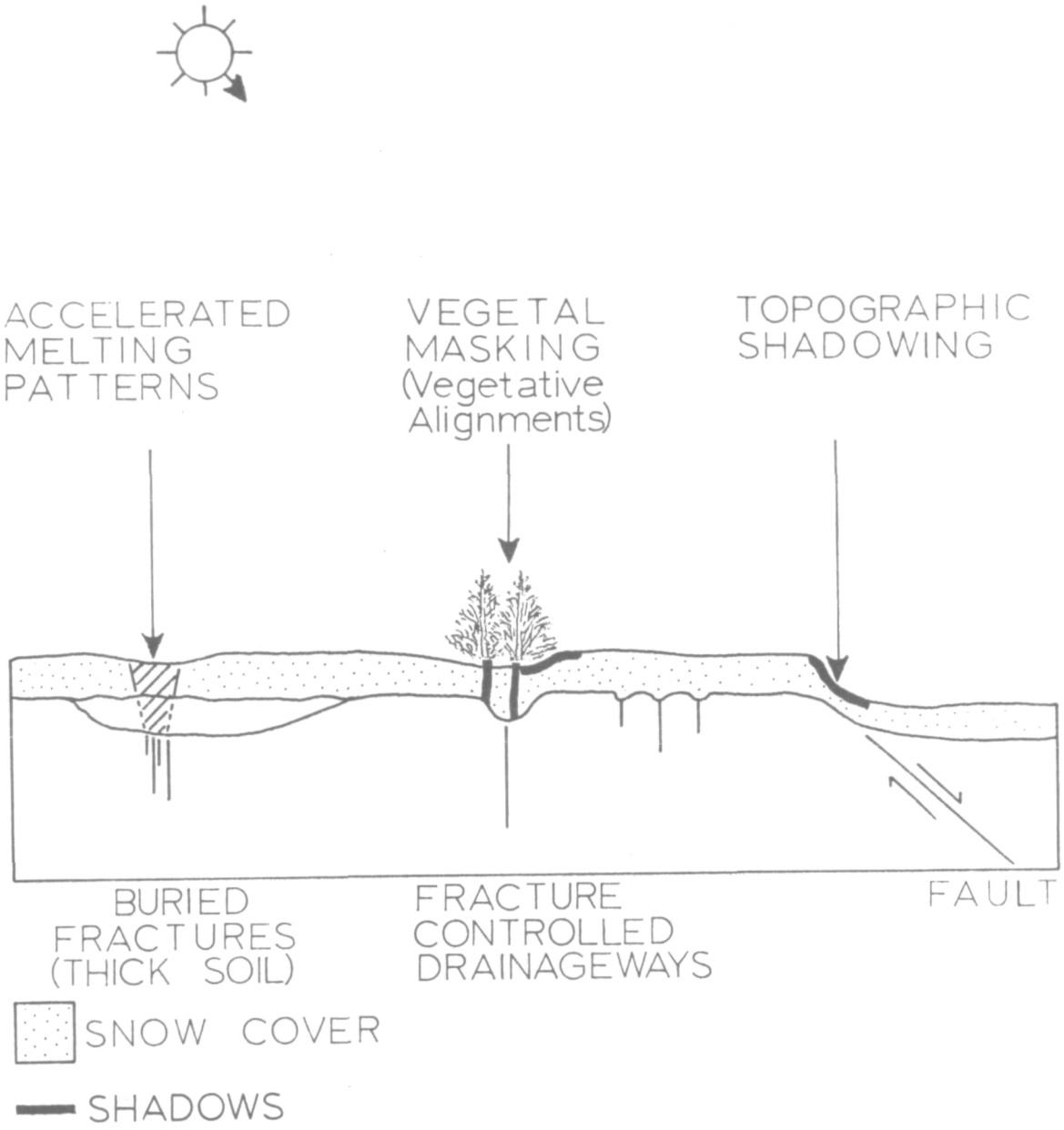


FIGURE 20: Mechanisms of snow enhancement identified from analysis of ERTS imagery, ERTS underflight photography and ground observations. Fractures are more detectable because of (a) accelerated melting rates in fracture zones producing diagnostic snow cover patterns (dark-toned lineaments), (b) vegetal masking of snow cover by vegetative overstory--alignments may be indicative of fracture control, and (c) topographic shadowing accentuated by low sun angle and high surface contrast which snow provides. Shadowing from vegetative alignments is also enhanced against a background of snow cover. The diagram assumes an even cover of snow with a depth of 1-4 inches.

The effects of depth on snow enhancement vary with the condition of the snow (e.g. water content, ablation rate, etc.). This is significant in that melt patterns are a key element in the enhancement provided by a new snow fall, i.e., dark tones are characteristically associated with areas of moist soil cover. As snow depth increases, the enhancement provided by melting snow decreases.

Less than one inch of snow cover provides a minimal enhancement for geological fracture detection. However, the enhancement effect increases with 1-4 inches of snow; above 4 inches the only enhancement of fractures is provided by topographic and vegetative alignments. Enhancement by topographic shadowing increases with snow depth to an undetermined upper limit. The limiting factor is that the snow surface must continue to conform to the surface of the underlying topography. In deep snow areas, snow drifting may reduce or eliminate conformance with terrain contours thus negating the enhancement effects of snow cover.

5.3.4 Snow Melt/Accumulation Trends

Depths of snow cover before and after wintertime ERTS overflights were analyzed to determine if melt or accumulation trends existed at the time of image acquisition. This was undertaken to evaluate whether snow enhancement was a more effective technique during periods of rapidly changing snow depth (e.g., new snowfall or snow melt) or during static conditions. Snow depth trends for four ERTS wintertime overpasses are displayed in Figure 21. The trends established in the test area were of insufficient magnitude to positively determine the situation under which snow enhancement yielded maximum results. However, related analyses suggest that melting trends or new snowfall accumulation in moderate amounts provide greater enhancement than static conditions. Analysis of April 7 ERTS imagery of southern Vermont (melt condition) supports this contention. Drainage patterns of this area are conspicuously enhanced during this period of melt.

5.3.5 Slope Aspect

Based on field and light aircraft observations, slope aspect has the greatest effect of any factor on snow melting patterns after a medium snow cover has been deposited (e.g. 3 inches). South-facing slopes were, as expected, generally snow-free following a period of extended melting even in areas generally described as having a continuous snow cover. Snow

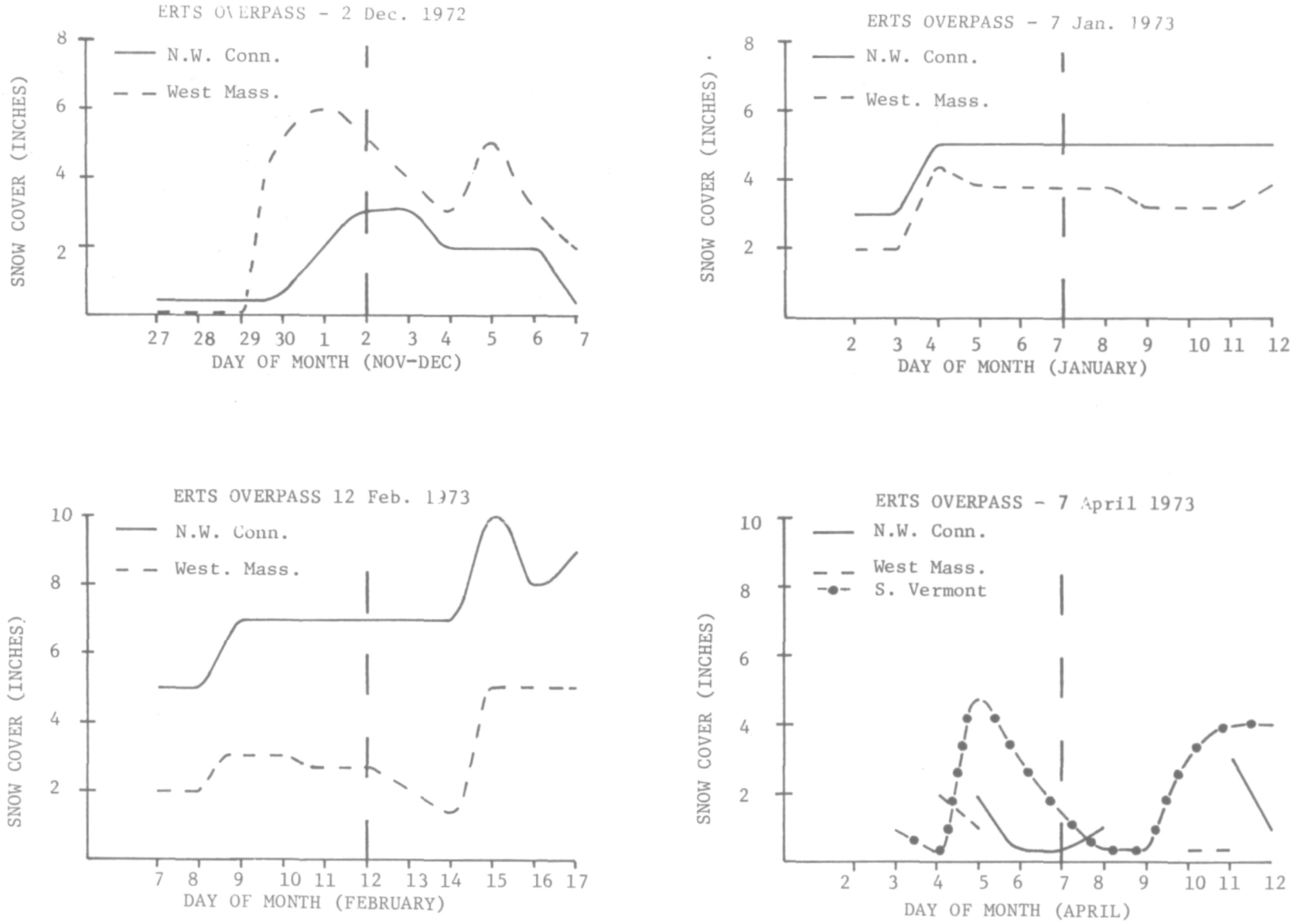


FIGURE 21: Illustration of snow melt and accumulation trends at the time of four selected ERTS overpasses of the New England Test Area. Snow depth data from selected sites have been plotted both before and after the date of the overpass to establish whether the image was acquired during a period of snowfall, snow melt or under static conditions. These graphs represent an average of snow depth readings and indicate that a static condition existed at many sites during the ERTS overpasses. It was hypothesized from pre-ERTS analysis that imagery collected during periods of rapid snow melt or accumulation would have supplied even greater fracture detail than static snow cover conditions.

cover was thickest in deep narrow valleys, and on high mountain slopes. Snow cover was thinnest on windswept open areas such as hilltops and in urban areas.

5.4 Technique Demonstration in New England Test Area

5.4.1 General Test Area

Following the completion of a regional reconnaissance fracture-lineament map for the New England Test Area, test sites were selected to demonstrate the application of snow enhancement for geological analysis. Analysis and field checking of these test sites was a simulation of the effort that might be expended by a field geologist in conducting studies preliminary to quadrangle mapping.

A multisensor data analysis of each test site was conducted following analysis of ERTS-1 imagery. The fracture-lineament validation system was then applied. A good correlation was found between the major fracture-lineament directions interpreted from various multi-sensor images (including snow-free and snow-cover ERTS imagery) and the strike of bedrock joints recorded in the field. This is a strong indication that the fracture-lineaments interpreted from ERTS imagery are expressions of bedrock structure. Because of a more intensive effort within the Great Barrington and Canaan Mountain Test Sites a greater number of lineaments were mapped and hence a greater residual set remained on the test site maps after validation compared to the Fracture-Lineament Map. A discussion of the analysis for each test site follows.

5.4.2 Great Barrington, Massachusetts Test Site

The Great Barrington area is located in Western Massachusetts and bounded by coordinates 73°05' - 73°20'W and 42°10 - 42°25'N (Figure 5). The area includes a portion of the western edge of the Berkshire Mountains on the east and segments of the Taconic Mountains on the west.

The Great Barrington Test Site was studied with the advantage of having five sources of remote sensor data available for fracture validation: Side-looking Airborne Radar (SLAR) imagery (1:500,000); Aero-Magnetic Data; U-2 Color Infrared Photography (1:120,000 scale); ERTS snow-free imagery (1:250,000). Supplementary color photography was acquired from a light aircraft to check fractures mapped from small scale imagery. Lineaments (including fractures and structural boundaries) were

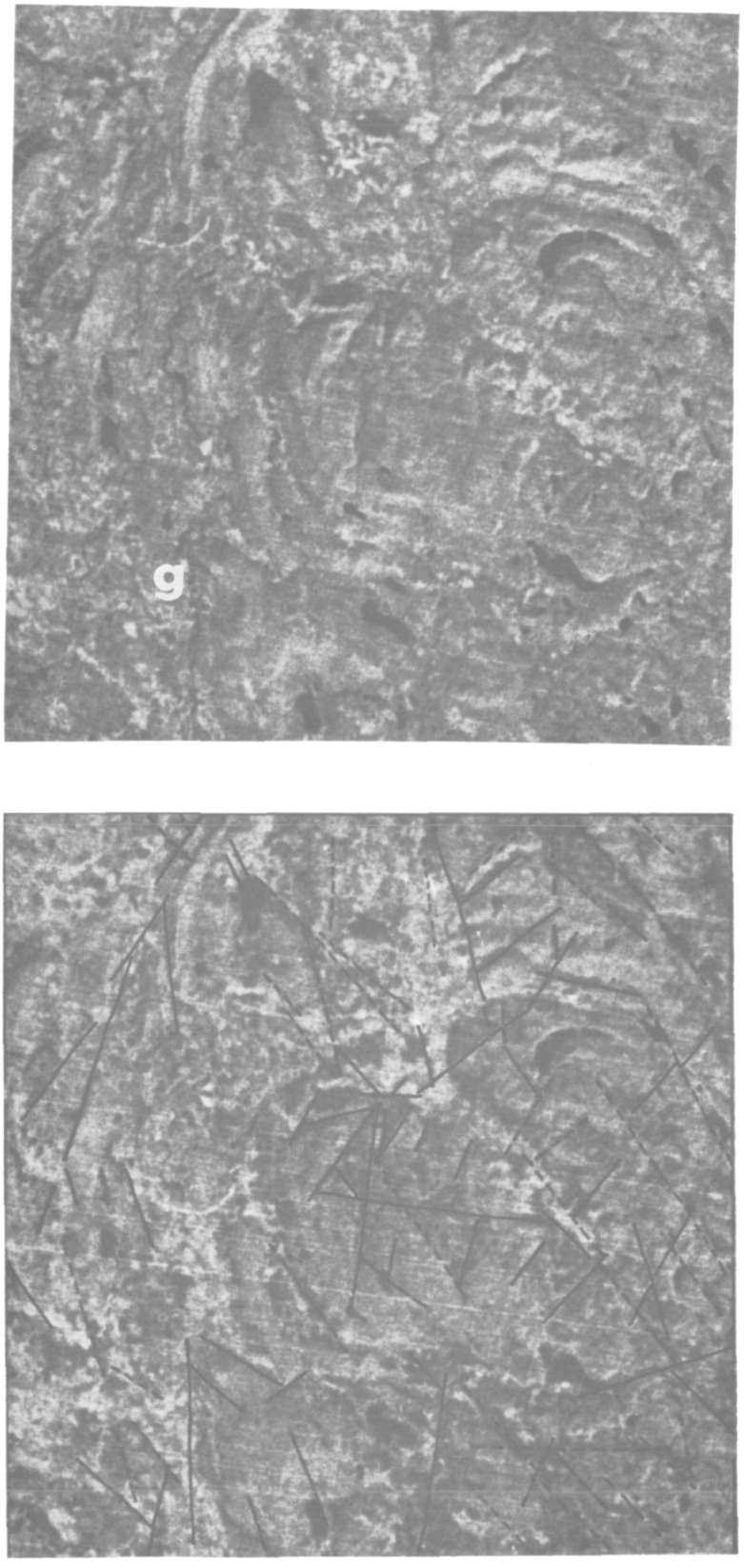
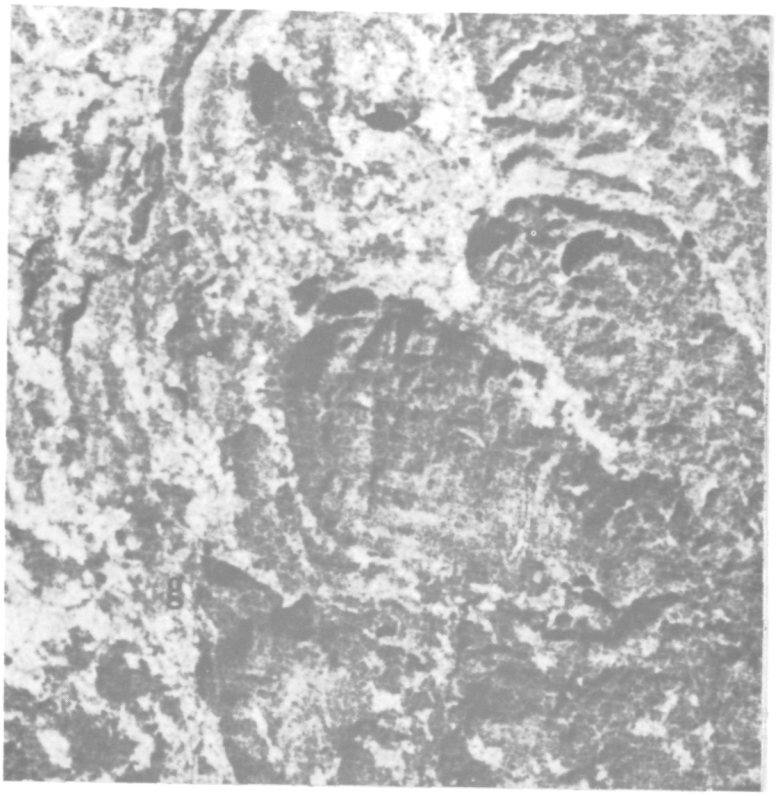


FIGURE 22: ERTS-1 snow-free image (1096-15072-7) of the Great Barrington, Massachusetts Test Site acquired on October 27, 1972. The town of Great Barrington (g) is identified as a geographic reference. Fracture-lineaments confirmed (———) and unconfirmed (------) by a sequential validation system have been mapped on Image B. The image is reproduced at a scale of 1:250,000.



A

B

FIGURE 23: ERTS-1 snow-enhanced image (1132-15074-7) of the Great Barrington, Massachusetts Test Site acquired on December 2, 1972. The town of Great Barrington (g) is identified as a geographic reference. Fracture-lineaments confirmed (_____) and unconfirmed (-------) by a sequential validation system have been mapped on Image B. Snow cover in this area was approximately 3-5 inches at the time of image acquisition. The image is reproduced at a scale of 1:250,000.

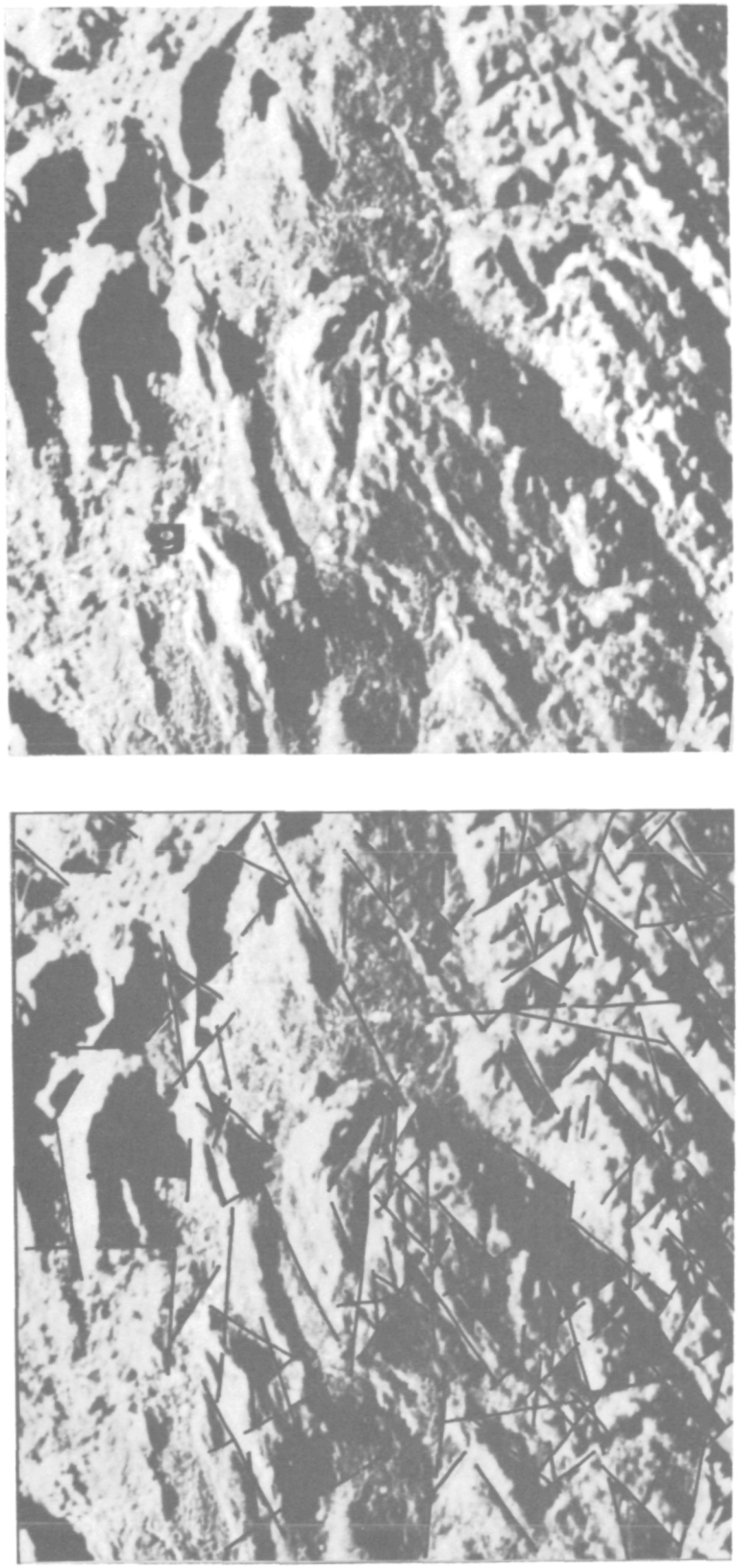


FIGURE 24: East-looking SLAR image of the Great Barrington, Massachusetts Test Site acquired May-June, 1970. The town of Great Barrington (g) is identified as a geographic reference. Fracture-lineaments (———) have been mapped on Image B. SLAR imagery (both east and west looking) has been used as a geological information source to aid in the validation of fracture-lineaments interpreted from ERTS-1 imagery. The image is reproduced at a scale of 1:250,000.

mapped using each data source. A study of the correlation between geological features interpreted from ERTS, aircraft data and available ground truth data (including field data collected by EarthSat and existing geologic maps) was conducted. An interpretation of the test site and an evaluation of the utility of each sensor for photogeological analysis follows.

5.4.2.1 ERTS Imagery (Snow Free)

An intensive analysis was conducted using the highest quality snow-free ERTS-1 image (1096-15072-7) of the Great Barrington Test Site which was acquired on October 27, 1972. Lineaments were identified from analysis of the ERTS-1 image (Figure 22). Sun elevation of this image was approximately 31° (above the horizon) at the time of overflight (azimuth 154°).

5.4.2.2 ERTS Imagery (Snow-Covered)

An ERTS snow-covered image (1132-15074-7) acquired on December 2, 1972 was analyzed in the same manner and with time-equivalent effort as was the snow-free image (Figure 23).1/ Interpreted linear data were validated and plotted on a fracture rose diagram for comparison with ground truth data and data obtained from the analysis of multi-sensor imagery (Figure 26). The thrust-faulted boundary of the Berkshire Massif is readily apparent on the snow enhanced image. The snow cover within the test site varied from 3-5 inches at the time of ERTS image acquisition. Numerous lineaments, identified by analysis of the low sun angle (22°) ERTS image, coincided with those mapped on the snow-covered high altitude CIR photography and SLAR imagery. Azimuth was 156° at the time of ERTS image acquistion.

5.4.2.3 Side-looking Airborne Radar (SLAR) Imagery

SLAR imagery enlarged to a scale of 1:250,000, was analyzed utilizing both east and west look directions. The east look direction provided the greatest amount of fracture-lineament data (Figure 24). Fracture-lineaments, faults, bedding and/or foliation trends were noted during the analysis.

1/Considerable time elapsed between the interpretation of the October 27 (snow-free) image and the December 2 (snow-cover) image and this reduced the importance of the learning factor in image analysis of the same site.

Interpretation of the SLAR imagery shows the thrust fault boundary of the Berkshire Massif, thrust fault slices and remnants of Taconic rocks to the west, and several smaller high-angle faults. Numerous fractures-lineaments were interpreted from the imagery (Figure 24). A summary of fracture-lineament plots shows a major direction between N30°W-N40°W and a secondary direction of N40°-50°W which does not correlate well with field measurements (Figure 26). This discrepancy may be related to distortions within the original SLAR imaging system or to distortions introduced in the radar mosaicking process.

5.4.2.4 USGS Aeromagnetic Maps

Aeromagnetic maps compiled by the USGS at a scale of 1:250,000 were obtained for the entire New England Test Area. To complement ERTS image analysis, an analysis of the Great Barrington Test Site was conducted utilizing this data (Figure 25). A study of the correlation between the magnetic anomalies and major structural trends interpreted from ERTS, SLAR, and CIR imagery was made. Fracture-lineaments interpreted from the snow-covered ERTS imagery correlate well with lineaments derived from aeromagnetic map analysis; however, short linear elements are not readily apparent on the aeromagnetic data. The use of ERTS imagery (especially imagery of snow covered terrains) in combination with aeromagnetic data could provide an important complementary tool for regional structural analyses, and ultimately mineral exploration.

5.4.2.5 High Altitude Color Infrared Photography (Snow-Covered)

Snow-covered color infrared aerial photography of the Great Barrington Test Site was acquired on January 31, 1973 by U-2 aircraft at a scale of 1:120,000. The photography served as a source for validation of geological features mapped using ERTS imagery. A number of more subtle and generally shorter linear features were identified using CIR photography that were not evident using SLAR or ERTS imagery. This was attributed primarily to the greater resolution of the CIR photography which enabled the detection of fine linear systems beyond the normal resolution of the other sensors. A summary plot of the orientation of fractures mapped on the CIR correlated to a higher degree with the ground truth data than any of the other sensors which were utilized. Dominant fracture directions were N20° -40°W, N80° -90°W, and N30° -50°E.

FIGURE 25a: Tectonic sketch map made from analysis of snow covered ERTS image in Fig. 23. All delineation is inferred and has not been field checked. ~~~~ = thrust faults, ~~~~ = high angle faults, ——— = major fractures, ——— = foliation direction, ····· = lithologic contacts.

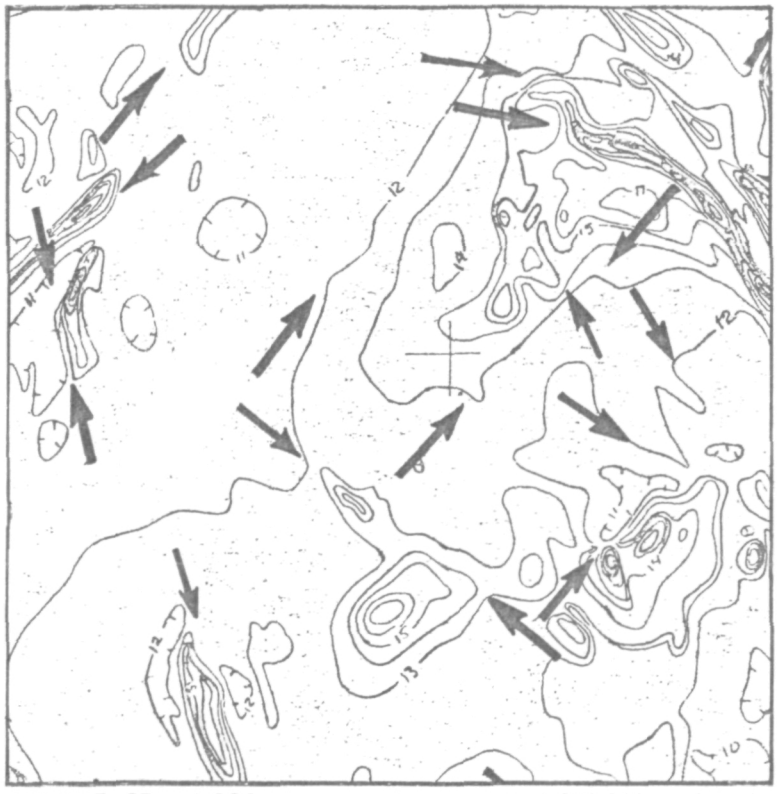


FIGURE 25b: USGS aeromagnetic map at 1:250,000 scale of the Great Barrington Test Site. Arrows point to linear magnetic anomalies and anomaly separations which correlate with fractures mapped from ERTS-1 and SLAR imagery.

5.4.2.6 Low Altitude (Light Aircraft) Oblique Color Photography

A light aircraft (Cessna 160) overflight of the New England Test Area was made on February 12, 1973. The area was predominately snow-covered at the time of overflight. Both photographic and visual observations were made to complement the perspective of ground field checking.

Several areas of intense fracture development were observed. Enhancement of geological features (such as fractures, bedrock dip, cleavage, and foliation) by differential snow cover was observed.

5.4.2.7 Results and Conclusions

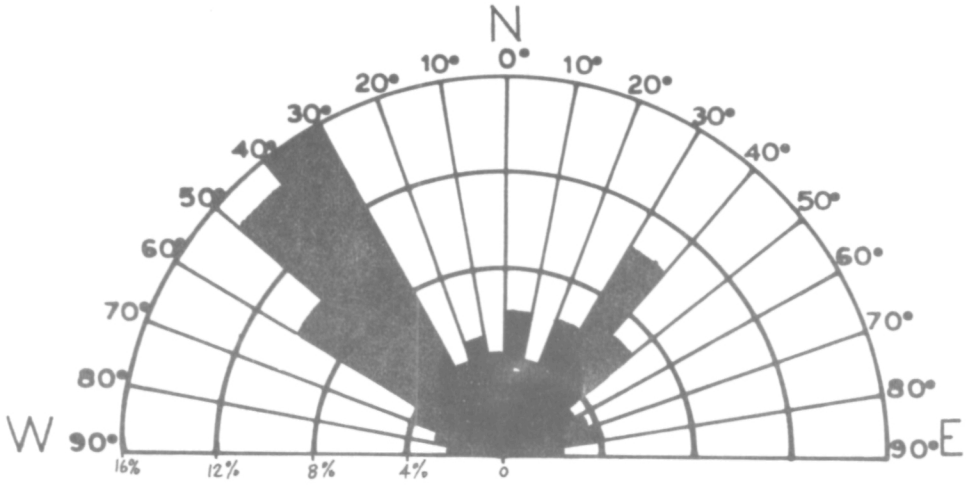
A comparison of the linear geological features (e.g., thrust faults, fracture-lineaments, etc.) interpreted from ERTS and those interpreted from complementary multi-sensor data shows a high degree of correlation. Comparison with other imagery reveals that a majority of fracture-lineaments and structural trends were not as evident on the ERTS snow-free image. This was attributed to the lack of a contrasting medium (e.g., snow) which would accentuate structural features. The investigators again emphasize the need for multi-seasonal, repetitive coverage in order to obtain comprehensive geological information from ERTS imagery.

The snow-covered ERTS image yielded considerably more geological information than the snow-free image and only slightly less than aircraft (U-2 CIR) imagery. The abundance of lineaments mapped using CIR photography was attributed to the greater resolution (and larger scale) of the CIR which facilitated the detection of subtle fractures beyond the resolution of the other sensors.

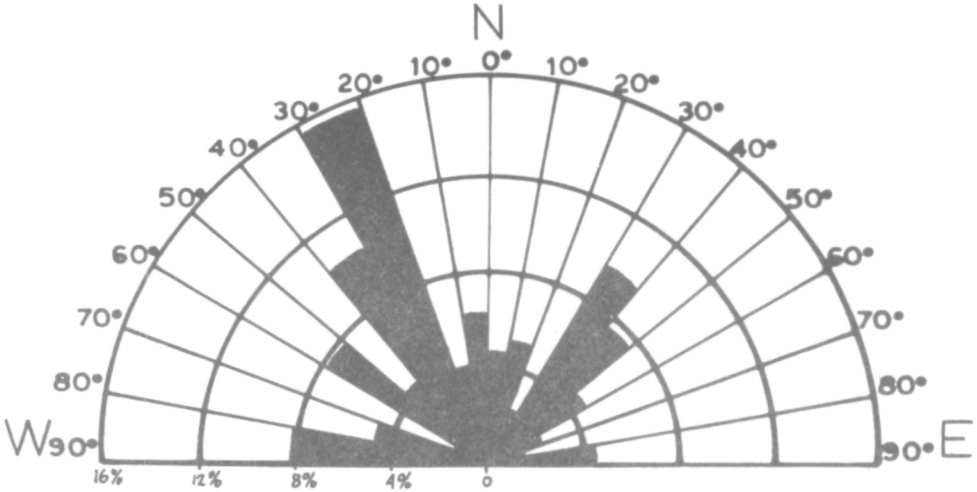
A strong correlation exists between the major fracture-lineament directions and the strike of bedrock joints mapped in the field (Figure 26). Most of the linear features interpreted from the various types of imagery are therefore judged to be surficial expressions of the structural configuration of the bedrock.

5.4.3 Canaan Mountain Connecticut Test Site

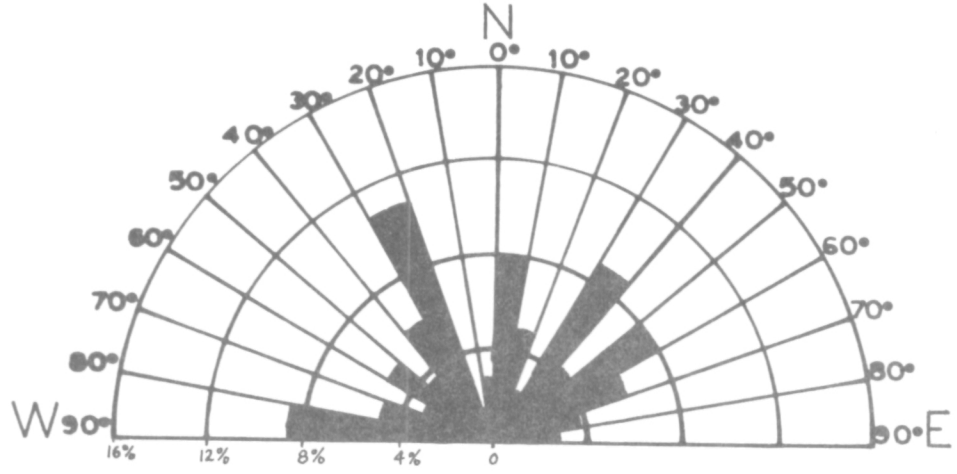
The Canaan Mountain site (Figure 5) is located in northwestern Connecticut and is bounded by coordinates 41°45'N - 42°00'N and 73°15'W - 73°30'W. The area includes portions of the western edge of



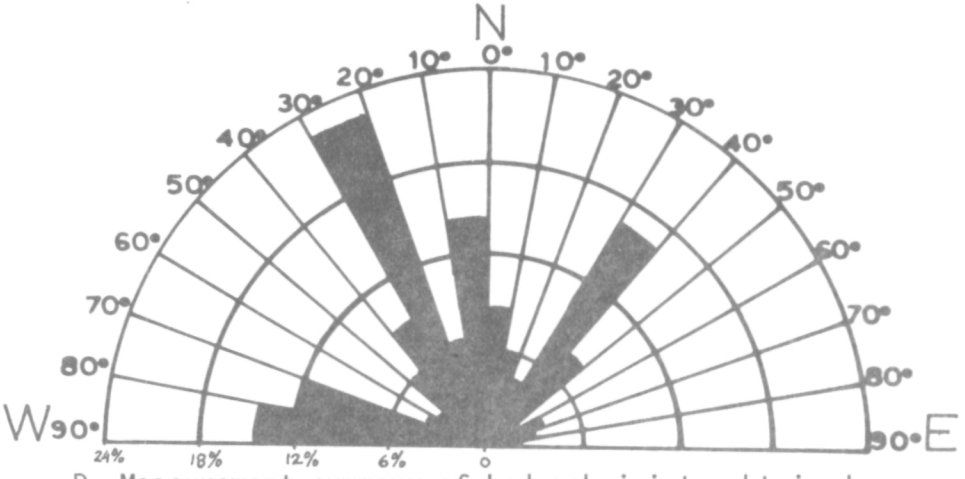
A. Measurement summary of fractures interpreted from SLAR imagery acquired with an east-look (azimuth 90°) direction, elevation 10°-30°.



B. Measurement summary of fractures interpreted from vertical (color infrared) U-2 imagery (snow covered).



C. Measurement summary of fractures interpreted from ERTS-1 snow-covered imagery. Sun angles: azimuth 156°, elevation 22°.



D. Measurement summary of bedrock joints obtained from field investigations.

FIGURE 26 : Rose diagram directional summaries of geologic fractures interpreted from multi-sensor imagery of the Great Barrington, Massachusetts test site.

the Berkshires (Housatonic Highlands) on the east, and segments of the Taconic Mountains on the west.

The major structural elements of the Canaan Mountains area include the Housatonic Highlands, the Canaan Mountain salient, and the Taconic Mountains and surrounding lowlands.

5.4.3.1 ERTS Imagery (Snow-Free)

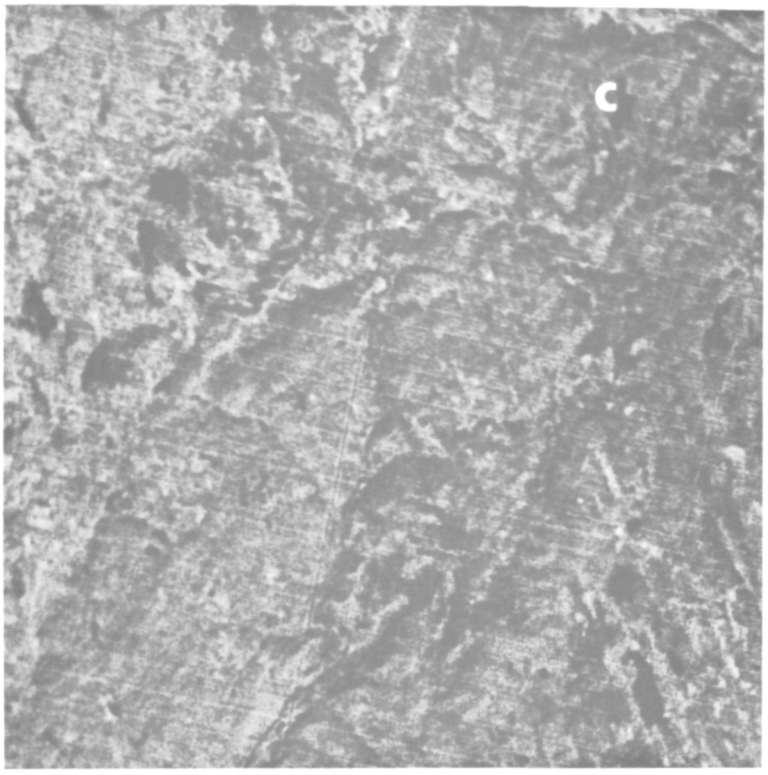
Analysis of a snow-free ERTS image (1096-15072-5) acquired on October 27, 1972, resulted in the detection of 104 fracture-lineaments. Sun angle was 31° (azimuth 154°) and deciduous vegetation was generally leaf free except in the southern part of the test area. Major structural boundaries and faults were not readily observed on the snow-free ERTS imagery (Figure 27). Predominant directions of the fracture-lineaments mapped from analysis of the snow-free image are between North and N30°W. N20°-30°W is the primary direction and N30°40° is the secondary direction.

5.4.3.2 ERTS Imagery (Snow-Covered)

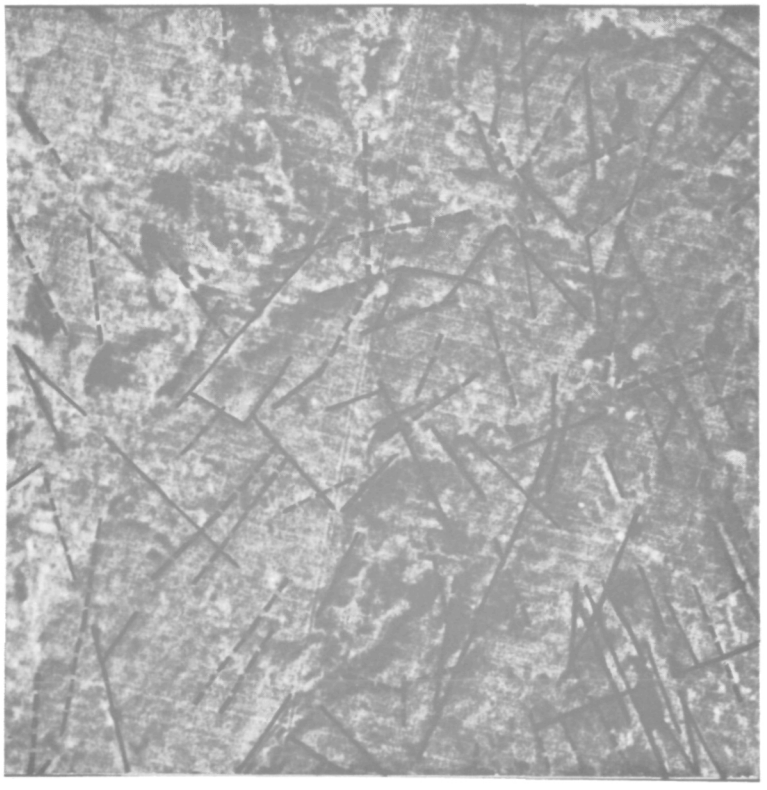
An ERTS-1 snow-covered image (1204-15074-5) acquired on February 12, 1973, was analyzed for the same period of time as the snow-free ERTS image (Figure 28). The sun angle (28°) and sun azimuth (146°) are similar to that of the snow-free image. Snow cover within the test site generally varied from 1 to 4 inches at the time of image acquisition.

The major structural boundaries of the area are prominent on the image. Snow cover has enhanced topographically expressed features in the Canaan Mountain and Housatonic Highlands areas. A total of 195 fracture-lineaments were mapped and plotted on a rose diagram for comparison with ground truth and data obtained from other sensors (Figure 31).

Snow cover enhanced both relief-expressed features and vegetative alignments enabling the investigators to detect nearly twice as many fracture-lineaments as with the snow-free ERTS imagery. The major directions of N30°-40°E and N20°-30°W appear on the rose diagram for the snow-covered images; the most prominent direction based on field measurements is N10°-20°W. Slight directional variations are attributed to the decrease in background "noise" that snow cover provides. Many additional and more subtle fracture-lineaments which are obscured by extraneous surficial detail on the snow-free ERTS image, were detected on the snow-covered image.

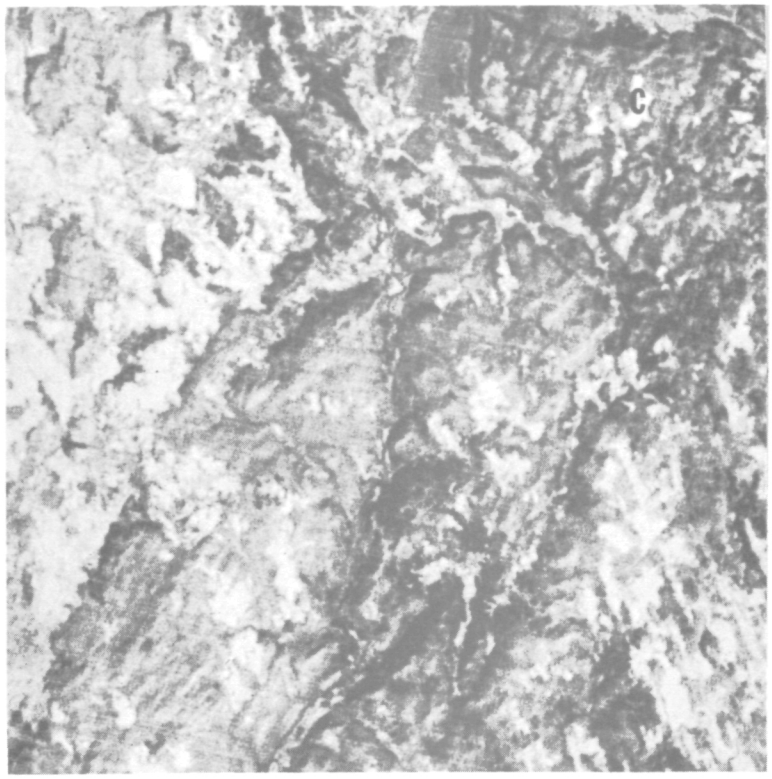


A



B

FIGURE 27: ERTS-1 snow-free image (1096-15072-5) of the Canaan Mountain (c) Test Site in the northwestern corner of Connecticut. The image was acquired on October 27, 1972 and is reproduced at a scale of 1:250,000. Fracture-lineaments confirmed (_____) and unconfirmed (-----) by a sequential validation system have been mapped on Image B.



A

B

FIGURE 28: ERTS-1 snow-enhanced image (1204-15074-5) of the Canaan Mountain (c) Test Site acquired on February 12, 1973. Fracture-lineaments confirmed (——) and unconfirmed (----) by a sequential validation system have been mapped on Image B. Snow cover within the test site was approximately 1-4 inches. The image is reproduced at a scale of 1:250,000.

5.4.3.3 Side-Looking Airborne Radar

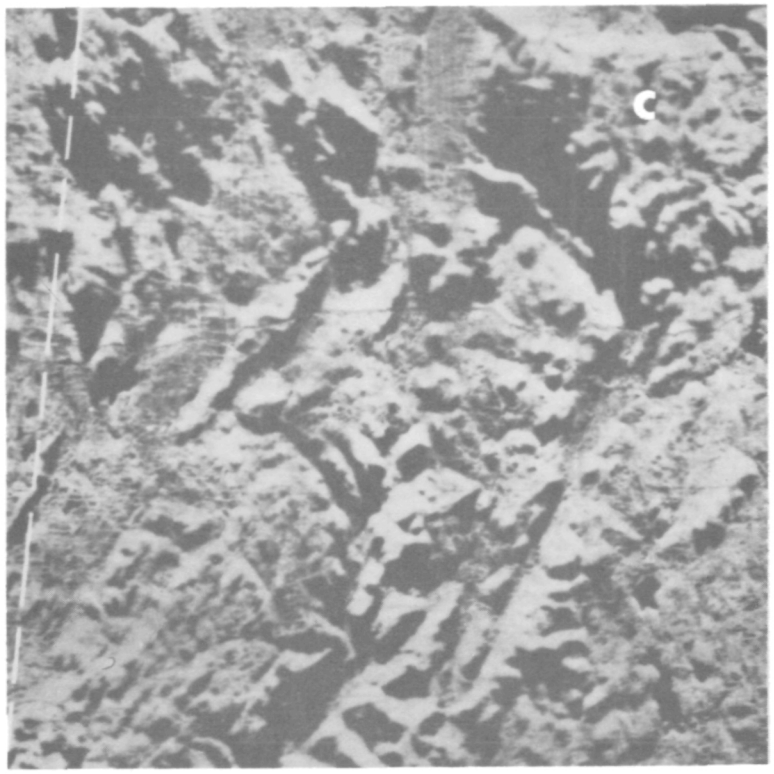
SLAR imagery acquired with both east and west looking direction was also analyzed for the Canaan Mountain Test Site. Fracture-lineaments detected from SLAR analysis were recorded and used for substantiating the fracture-lineaments mapped on ERTS imagery (Figure 29). The SLAR imagery shows the thrust boundaries of the Housatonic Highlands, the Canaan Mountain salient and the Taconic klippen which stand above the surrounding carbonate lowlands, and some of the high angle faults shown on the geological map (Figure 7).

A summary of the 150 fracture-lineaments (Figure 31) mapped using SLAR imagery shows a major direction between N30°E and N40°E, and a secondary direction between N20°W and N30°W. These directions correlate well with bedrock joint measurements obtained in the field (Figure 31). The directions also correlate well with the principal directions mapped from the snow-free ERTS imagery. The snow-covered ERTS image summary indicates a primary direction between N10°W and N20°W, and it shows the N30°- 40°E orientation as a secondary direction. This is probably due to the fact that the differential cover of snow accentuated subtle fractures with subdued topographic expression which could not be detected using the snow-free ERTS or SLAR imagery. A similar result was obtained in the analysis of the Great Barrington Test Site.

5.4.3.4 Aeromagnetic Maps

Aeromagnetic data of the Canaan Mountain Test Site was analyzed to define major magnetic lineaments (Figure 30). The marbles and schists of the Taconic synclinorium are of low magnetic intensity while Canaan Mountain and the Housatonic Highlands have relatively high magnetic intensities.

Comparison between magnetic anomalies and major structural trends interpreted from ERTS and SLAR imagery indicates that major fracture-lineaments interpreted from the imagery correlate well with aeromagnetic lineaments. However, relatively short linear elements are not readily apparent on the aero-magnetic maps. Canaan Mountain is of special interest; it appears as a series of small aeromagnetic anomalies separated by linear areas of low magnetic intensity. These linear "lows" correlate with fracture-lineaments which are best seen on the snow covered ERTS imagery and which may be fracture zones which have been intruded by dikes or veins of non-magnetic mineral.



A

B

FIGURE 29: East-looking SLAR image of the Canaan Mountain (c) Test Site acquired May-June, 1970. Fracture-lineaments (———) have been mapped on Image B. SLAR imagery (both east and west looking) has been used as a geological information source to aid in the validation of fracture-lineaments interpreted from ERTS-1 imagery. The image is reproduced at a scale of 1:250,000.

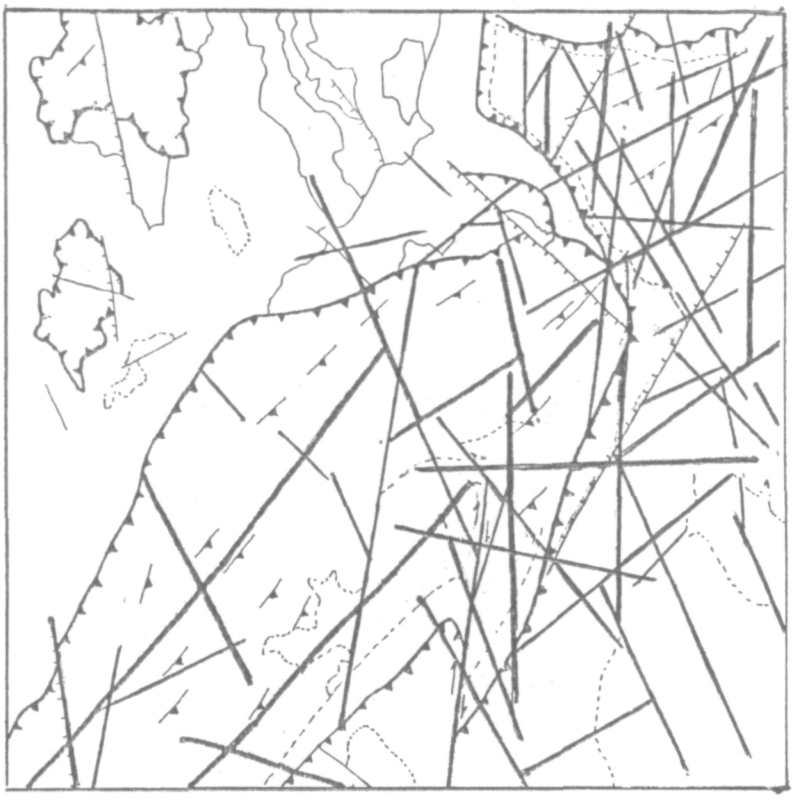


FIGURE 30a: Tectonic sketch map made from analysis of snow covered ERTS image in Figure 28. All delineation is inferred and has not been field checked. = thrust faults, = high angle faults, = major fractures, = foliation direction, = lithologic contacts.

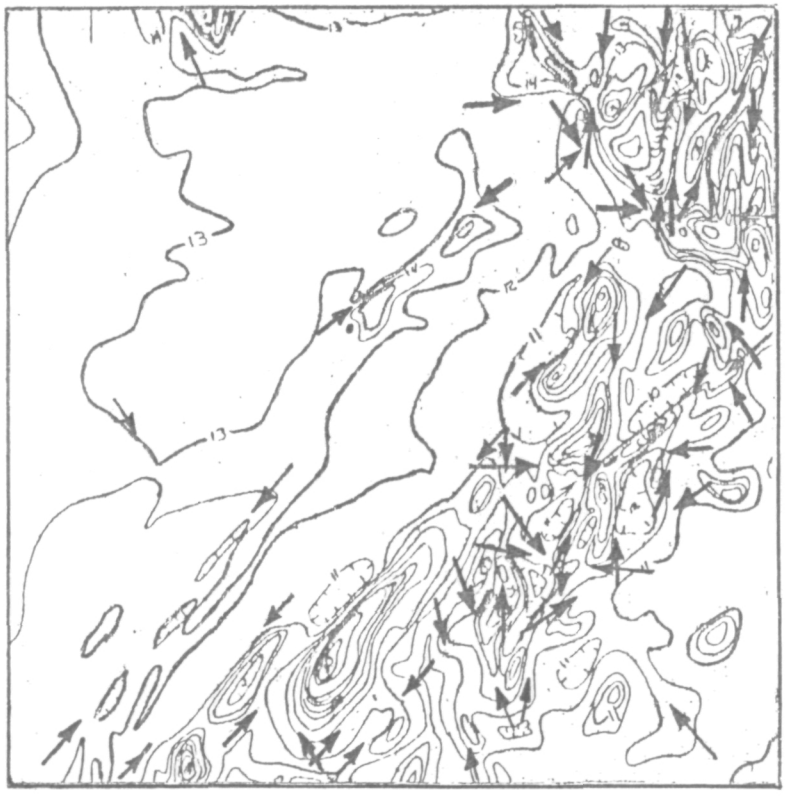
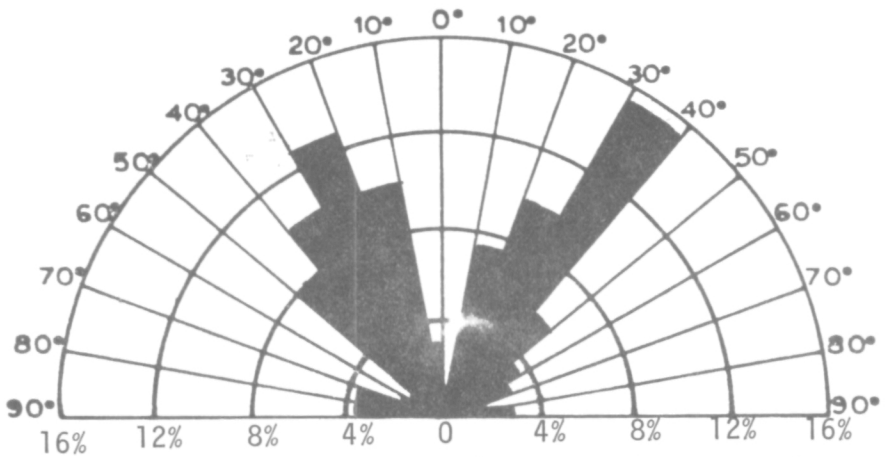
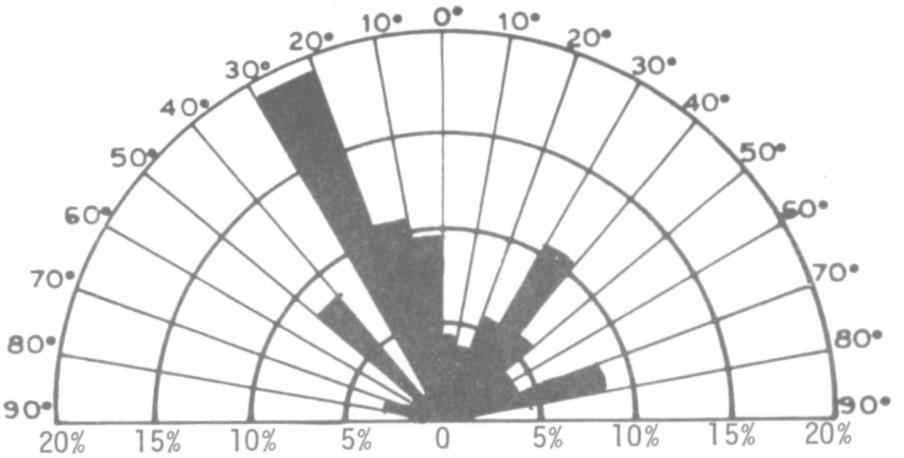


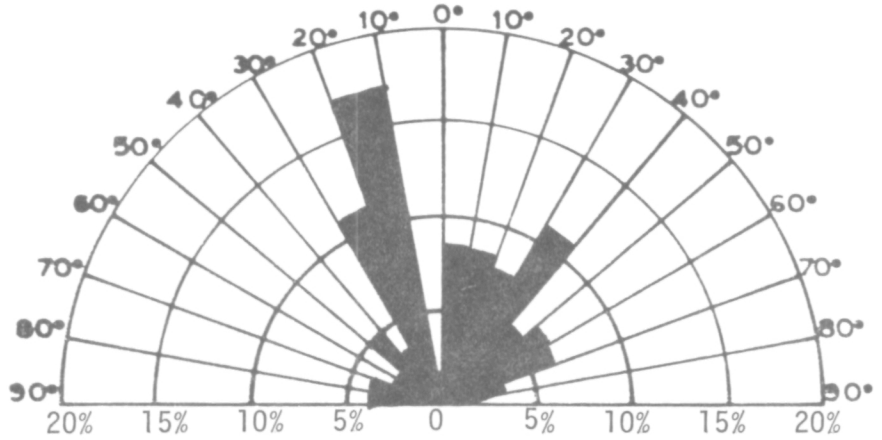
FIGURE 30b: USGS aeromagnetic map at 1:250,000 scale of the Canaan, Connecticut test site. Arrows point to linear magnetic anomalies and anomaly separations which correlate with fractures mapped from ERTS-1 and SLAR imagery.



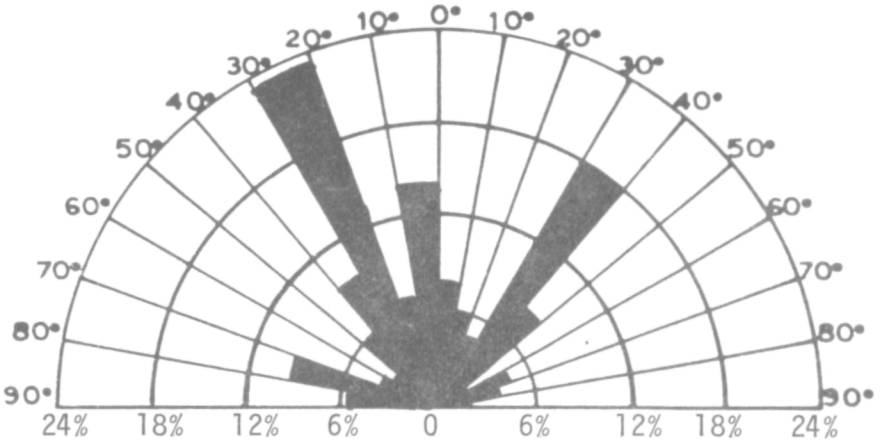
A. Measurement summary of fractures interpreted from SLAR imagery acquired with an east-look (azimuth 90°) direction, elevation 10°-30°.



B. Measurement summary of fractures interpreted from ERTS-1 snow-free imagery. Sun angles: azimuth 154°, elevation 31°.



C. Measurement summary of fractures interpreted from ERTS-1 snow-covered imagery. Sun angles: azimuth 146°, elevation 28°.



D. Measurement summary of bedrock joints obtained from field investigation.

FIGURE 31: Rose diagram directional summaries of geologic fractures interpreted from multi-sensor imagery of the Canaan Mountain test site.

5.4.3.5 High Altitude Color Infrared Photography

Underflight coverage was not acquired for the Canaan Mountain area.

5.4.3.6 Results and Conclusions

A tectonic sketch map (Figure 30) was prepared from the analysis of the snow-covered ERTS image (1204-15074-5) of the Canaan Mountain Test Site. All known thrust and high angle faults were detected on the image and numerous suspect faults were also observed. Major fracture systems have been annotated and foliation directions plotted on the sketch map. General lithologic contacts which aided the delineation of the structure of the area, were detected based on image tonal differences. The unique fracture pattern, image tone, and relief noted on the ERTS image adds credence to the interpretation that the Canaan Mountain salient ("C" in Figure 27) is allochthonous, having been thrust westward over the Stockbridge marble in the Taconic synclinorium.

Sun angle, although an important factor in accentuating topograhic relief, did not effect the comparative snow-free versus snow-covered image data yields since sun angles were nearly the same (31° for snow-free, 28° for snow-covered). A total of 104 fractures were mapped from the snow-free image, 150 fractures from the SLAR image, while 195 were detected on the snow-covered image. This again emphasizes that snow enhancement can contribute information not available using other remote sensors or snow-free imagery.

The difference in the numbers, spacing, and orientation of fractures mapped on the various types of bedrock is also significant. Fractures in the older thrust-faulted crystalline rocks of the Housatonic Highlands and Canaan Mountain are prevalent in at least four dominant directions and are much more numerous and closely spaced than the fractures within the Cambrian and Ordovician metasedimentary rocks west of the Berkshire thrust zone. The metasedimentary rocks are less intensively fractured having only two dominant fracture directions. This suggests that the crystalline rocks underwent at least one more period of stress. Acquisition of such information emphasizes the value of systematic fracture analysis for determining multiple periods of tectonic activity, even in complex areas having limited bedrock exposures.

5.4.4 Acquisition of New Geological Data

Existing fracture and fault data for the New England Test Area was collected from available open sources to provide information which could be used in the confirmation of lineaments interpreted from ERTS imagery.

Fractures (faults) from existing maps were plotted on topographic map sheets at the same scale as the Fracture-Lineament Reconnaissance Map to facilitate comparative analysis. The lengths and number of fractures from the existing sources and from the ERTS analysis were then totalled. All fracture information including that indicated by solid, dashed or dotted lines with question marks was included within the total extracted from the existing sources; only those fracture-lineaments confirmed by the sequential validation system (solid lines) were included in the ERTS fracture total.

The total length of validated fracture-lineaments interpreted from ERTS imagery was greater than the total of existing data (available to the investigators) for the New England Test Area by a factor of three. Within the selected test sites an even greater ratio of new to existing data was obtained due to the more intensive analysis which was conducted within these areas. It should be noted that the fracture-lineaments included as new data were validated and, therefore are likely to contribute new data to field geologists involved in quadrangle or regional mapping operations within New England. Further analyses of ERTS imagery at the level of those conducted for the two test sites would result in an even greater accumulation of new fracture-lineament data which could resolve structural problems in some areas of New England.

While it is not expected that all fracture-lineaments will ultimately prove to be expressions of bedrock fractures (despite a systematic validation), the investigators suggest that important candidate structural data is now available and that much of it will prove useful.

5.5 Other Geological Applications

5.5.1 Discrimination of Lithological Units

Snow-enhanced ERTS images are more efficient to use than snow free ERTS images for discriminating broad lithological differences. Snow-cover provides a basis for discriminating lithological differences by contrasting macro relief and by highlighting terrain texture, i.e., the integration of

geomorphic variations, vegetation and drainage patterns (Figure 32). Specific data provided by snow-enhancement that were observed to be of value in aiding lithologic identification are grouped into the following categories:

5.5.1.1 Differentiation of Fracture Patterns

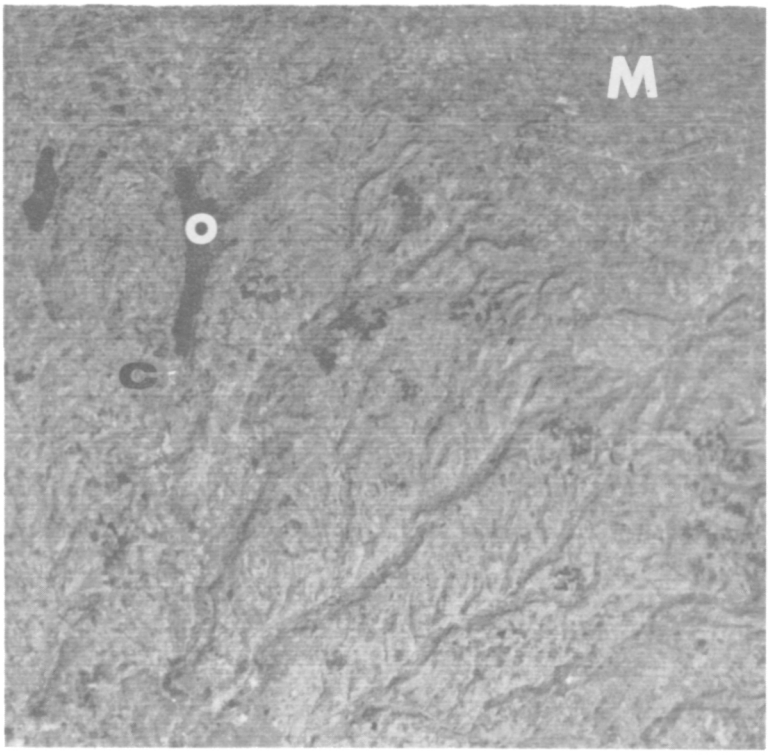
Enhancement of linear features by snow cover enables a more comprehensive geological analysis of fracture patterns which are indicative of gross rock type. For example, the Precambrian basement rock of the Adirondacks, Berkshires and Hudson Highlands (granitic gneisses and metasedimentary rocks) exhibits a distinct NE-SW lineament trend. The Adirondack rocks exhibit a rectangular joint pattern which permits them to be differentiated from the Berkshire and Green Mountain rocks using ERTS color composites complemented by snow enhanced ERTS images.

5.5.1.2 Vegetation Patterns

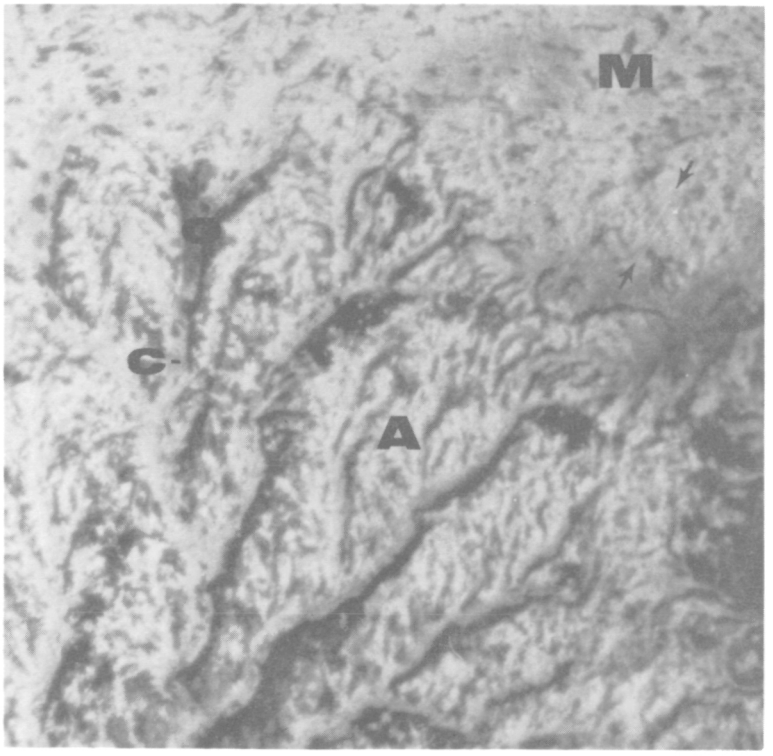
The coniferous vegetative cover of some upland areas in New England contrasts sharply with exposed bedrock outcrops which are frequently snow-covered. This often serves to accentuate those rock types (e.g., arenaceous, and quartz-rich) which provide suitable growing sites for coniferous trees.

5.5.1.3 Geomorphic Patterns

Drainage patterns which are enhanced by snow cover provide indicators of general rock lithology. Rectangular (fracture controlled) drainage is often associated with Precambrian metamorphic rocks such as those in the Adirondacks. Snow enhanced ERTS images of New England show some similar patterns in the Berkshires and Hudson Highlands. Weathering on a macro-scale produces variations in roughness or texture for differing lithologies, which is further enhanced by snow cover. Relief differences between the Triassic Connecticut Basin and adjacent metamorphic uplands are enhanced by snow cover; general judgements can be made with regard to variations in resistance to weathering and texture.



A



B

FIGURE 32: ERTS-1 images of the Appalachian Uplands and Mowhawk Lowlands area, New York (1:500,000 scale). Ostego Lake (o) and Cooperstown (c) are included as geographic references. Image A (1079-15122-5) was acquired October 10, 1972. Image B (1169-15123-5) was acquired on January 8, 1973 and has a moderate-heavy snow cover. The combined factors of snow-enhancement and lower sun angle (20 degrees on January 8 vs. 36 degrees on October 10) accentuate the boundary between the physiographic provinces. The Appalachian Uplands (A) are characterized by a regional dendritic drainage pattern which has formed on south dipping rocks. The topographic expression of the more resistant sandstones and shales is enhanced by the tonal contrast provided by snow cover on Image B. The Mowhawk Lowlands (M) are under-lain by less resistant limestones and shales and are characterized by uniform land use, alignment and density of linear expressions, and surficial texture (arrows). Features described above are indicative of underlying rock types and were best seen on the snow-covered image suggesting the application of snow enhancement for small scale mapping of lithology and structure.

5.5.2 Environmental Geology

The concept of environmental geology involves the practical presentation and application of geological data in a form useful for regional planning, environmental management and land use control. During the conduct of the investigation, the states of Delaware, Massachusetts and Illinois expressed an interest in determining if geological and hydrological phenomena of value for environmental programs could be more effectively detected, discriminated and mapped with the assistance of snow enhancement than with manual techniques now routinely available. The results were obtained from studies of diverse terrain types in Northern Indiana, New Jersey and the New England area.1/

As a general rule, geomorphic or land use features characterized by species differences or variation in vegetative density from surrounding areas, were easily identifiable. Landforms along river systems such as oxbows and backswamp areas, were easily detected because their vegetative cover differed from that of surrounding areas. Terrace slopes were also detected on ERTS snow covered imagery within the Connecticut River Valley due to vegetative cover differences and topographic shadowing. Clear-cut areas and land under development were also conspicuously enhanced by snow cover. Deciduous/coniferous boundaries were accentuated as were agricultural field/forest interfaces and wetland/upland boundaries along coastal areas.

Urban centers (street patterns) and such cultural features as airports and transmission line right-of-ways were also enhanced by snow cover (Figure 33). Snow clearing operations, indicative of differing intensity of land use, clearly affect the image tone of urban areas and allow tentative intra-urban discriminations.

Identification of environmental geology applications with ERTS snow enhancement techniques will speed mapping and aid agencies unable to afford more complex and costly image enhancement devices. Further anticipated environmental geological applications of snow enhancement interpretation techniques are listed in Table 6.

1/ Analyses outside the test area were initiated to partially compensate for the proposed studies in the Maryland-Virginia Test Area which could not be conducted because of a lack of snow cover.

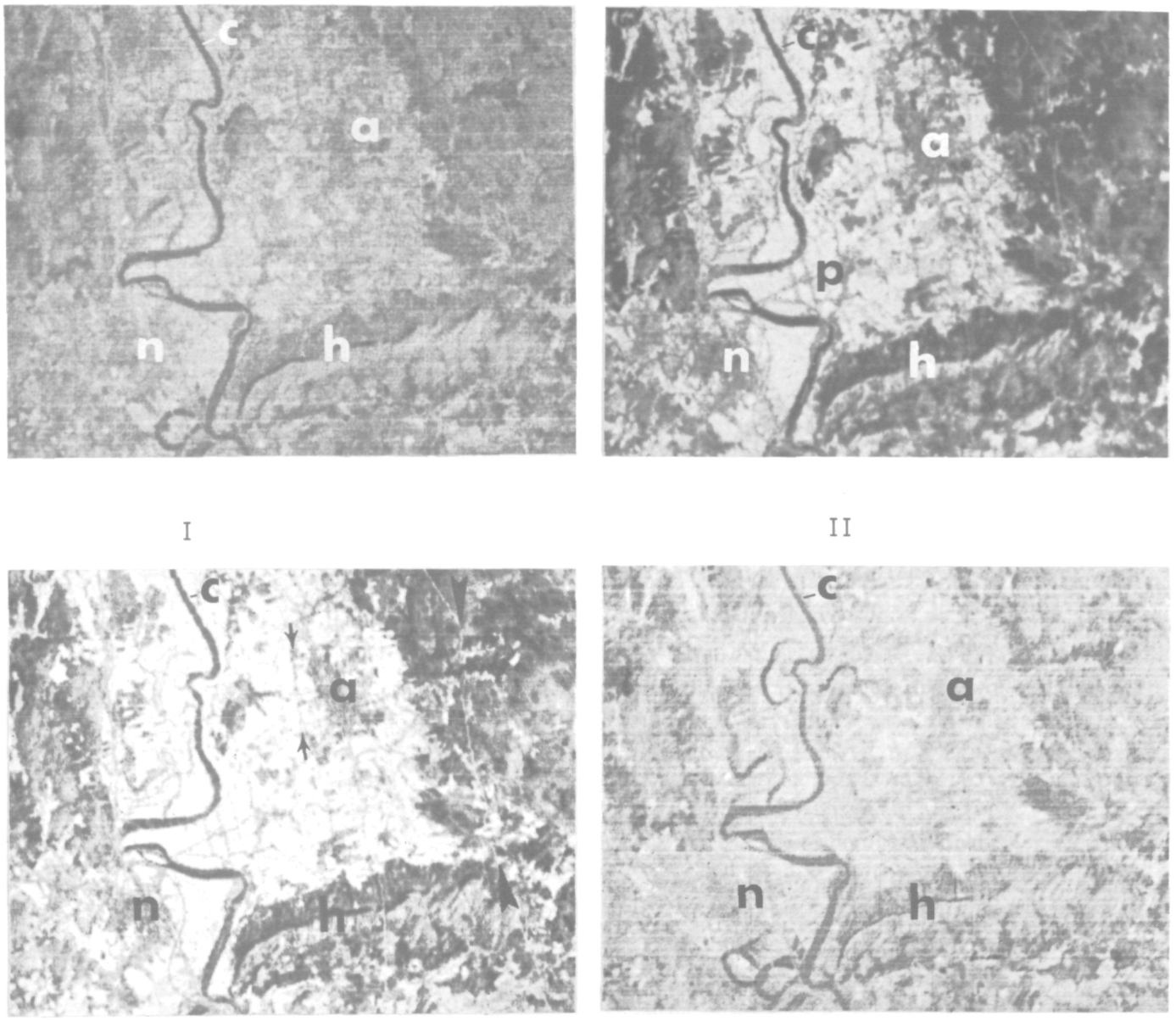


FIGURE 33: The above images were acquired by ERTS-1 MSS band 5 over central Massachusetts. The 1:250,000 scale images illustrate the influences of seasonal variations on the comparative detectability of cultural features utilizing snow-free and snow-covered imagery. Image I (1096-15065) was acquired on October 27, 1972. The Connecticut River (c) flows north-south on the image. Mt. Holyoke, a large diabase dike, occurs at (h). The towns of Northampton (n) and Amherst (a), Massachusetts cannot be reliably identified. No highway detail is visible on this image. Image II (1168-15065) was acquired on January 7, 1973. The area shows a light cover of snow (approximately 2 inches). Street patterns (p) can be more easily discerned on this image than on Image I. The urbanized area of Amherst (a) and the University of Massachusetts can also be more easily located. This is attributed to the increased contrast between snow-cleared urban areas and snow-covered rural areas. Image III (1204-15072) was acquired on February 12, 1973 and shows a slightly deeper snow-cover (approximately 4 inches). Transmission lines (large arrows) and roadways (small arrows) are readily visible. Image IV (1258-15080) was acquired on April 7, 1973. Snow cover is not evident on this low contrast image. Land use cannot be as readily distinguished on this image as on the snow enhanced images (II and III).

TABLE 6: ANTICIPATED ENVIRONMENTAL GEOLOGICAL APPLICATIONS OF SNOW ENHANCEMENT TECHNIQUES

Environmental Geological Investigative Area	Snow Enhancement Technique(s)	Anticipated Data Yield	Application(s) Examples
Flood-Prone Areas	Vegetal Snow Masking (difference in cover between valley slopes, terraces, and floodplains); Flooded Area Differentiation (flooded versus snow-covered surrounding areas)	• Areal Extents of Flood-Prone Areas	Flood Monitoring
Land Development	Vegetal Snow Masking (differences between snow-masked forest or partially masked low-growth vegetative cover and non-masked bare land)	• Recreational Road Patterns in Wilderness Areas; • Land Denudation for Development in Urban Fringe and Adjacent Agricultural Areas	Monitoring of Recreational Pressure and Impact on Natural Wilderness Resources; Monitoring of Loss of Prime Agricultural Land
Vegetative Surveys	Vegetal Snow Masking (accentuating vegetal differences by snow masking)	• Differences in Forest and Agricultural Types; • Recent Logging Patterns	Timber Volume Estimates, Automated Inventories of Woodlots, Pasture, or Winter Wheat During Winter Months

Table 6.

Environmental Geological Investigative Area	Snow Enhancement Technique(s)	Anticipated Data Yield	Application(s) Examples
Thermal Outfalls	Ice Melt Patterns	• Detection of Thermal Anomalies in Rivers, Lakes, and Reservoirs	Location of Groundwater Sources; Monitoring of Effluent from Thermal Power Plants
Ground Water Depth (near-surface) 1/	Snow Melt Patterns (high moisture content sub-surface materials will cause rapid melting; Changing Snow Cover Patterns (to monitor level of groundwater table)	• Detection of Near Surface Ground Water Tables	Location of Near-Surface Groundwater
Mineral Extraction	Snow Dusting (highlighting subtle topography of ridges in area mining); Vegetal Snow Masking (contrast between snow-covered bare areas and snow-obscured forests) (vegetative cover type differentiation on reclaimed areas)	• Location of Surface Mining Areas; • Stage of Reclamation; • Vegetative Cover Type on Reclaimed Areas	Monitoring Land Clearance and Excavation in Lands Adjacent to Active Mining Operations to Observe Mining Operations

1/ Estimated at 3 feet or less.

Table 6.

Environmental Geological Investigative Area	Snow Enhancement Technique(s)	Anticipated Data Yield	Application(s) Examples
Mined Land Subsidence	Snow Melt Patterns (negative topographic expression will accumulate moisture and melt-off more rapidly)	• Detection of Roof Collapse and Mine Subsidence	Facilitates Enactment of Zoning Restrictions Against Land Development in Unstable Areas
Burning Landfills	Snow Melt Patterns (thermal differential); Ice Melt Patterns (near water landfills)	• Detection of Burning Landfills	Facilitates Detection of Underground Fires in Sanitary Landfills
Solid Waste Disposal	Snow Melt Patterns (less permeable, finer materials melt-off more rapidly) (near surface ground water will cause more rapid melting); Vegetal Snow Masking (land use)	• Texture and Permeability of Surface and Near Sub-surface Materials; • Land Use Classification in Environmentally Critical Urban Fringe Areas	Site Selection for Solid Waste Disposal Sites

Table 6.

Environmental Geological Investigative Area	Snow Enhancement Technique(s)	Anticipated Data Yield	Application(s) Examples
Landform Mapping	Snow Melt Patterns (related to Texture and Permeability)	• Texture and Permeability of Surface and Sub-Surface Materials; • Differentiation of Landform Types	Location of Sources for Highway Aggregate

5.5.3 Mineral Exploration and Metallogenic Mapping

A study was conducted on the vaguely-defined "mineral belt" of northwestern Massachusetts (Quinn, 1967) to determine if ERTS imagery and in particular, snow enhancement techniques, could contribute to the understanding of the concentration of the ore deposits and to the exploration for other such deposits. The area investigated extends from west Cummington to about five miles north of Charlemont, Massachusetts (Figure 34). Within this area are several abandoned mines and prospects which were operated before 1940. The locations of the mines and prospects are shown (Figure 34). The ores of the "mineral belt" are divisible into two groups (Quinn, 1967): (1) manganese and iron silicates, carbonates and oxides, and (2) iron, copper, and zinc sulphides.

The area is underlain by three bedrock formations, the Savoy Schist and overlying Hawley Schist, both of Ordovician age, and the Silurian Goshen Schist. An oval-shaped body of gneiss occurs within the Savoy Schist near Plainfield Pond. The strike of the bedding and schistosity of the rocks is north-northeast; the rocks dip moderately to steeply to the east. The rocks are all in the lower part of the almandine-amphibolite facies of metamorphism. However, the ore deposits do not show effects of this metamorphism. Early geologic work done in the area suggested that the ore veins were mostly controlled by faults, but Quinn's work (1967) led him to believe that the deposits in the "mineral belt" were not located on faults.

A geological analysis of the area was conducted using snow-covered ERTS images along with snow-free ERTS images and U.S.G.S. aeromagnetic maps. More than 65 image lineaments were mapped in the "mineral belt" and surrounding area; all mines fell at or very close to the intersection of two or more lineaments. A strong north-northwesterly lineament trend (N20°W) is obvious on the ERTS fracture-lineament map (Figure 35a); it is noteworthy that all mines are crossed by this northwesterly trend. The mine locations are also intersected by northeasterly lineaments although there is no single predominant northeasterly trend.

To complement studies using ERTS snow enhanced imagery, aeromagnetic maps compiled by the U.S.G.S. were also studied. Regional aeromagnetic anomalies clearly delineate the "mineral belt" as the surrounding rocks are much less magnetic (Figure 35b). Although the mine locations do not coincide with any large magnetic anomalies, they are all situated at or near intersections of aeromagnetic "lineaments". Such lineaments are indicative of faults and large fractures which have changed the magnetic patterns in the deep

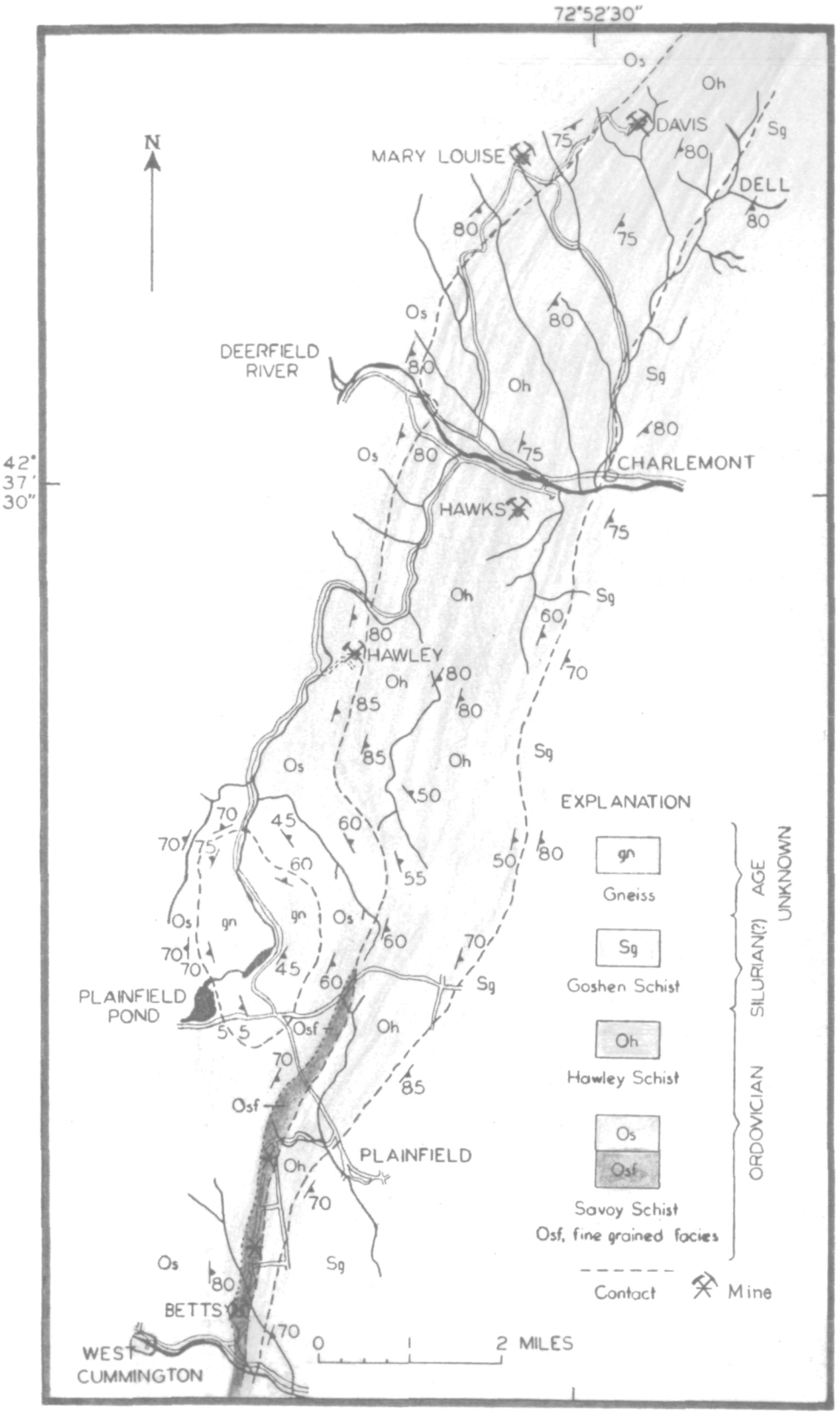
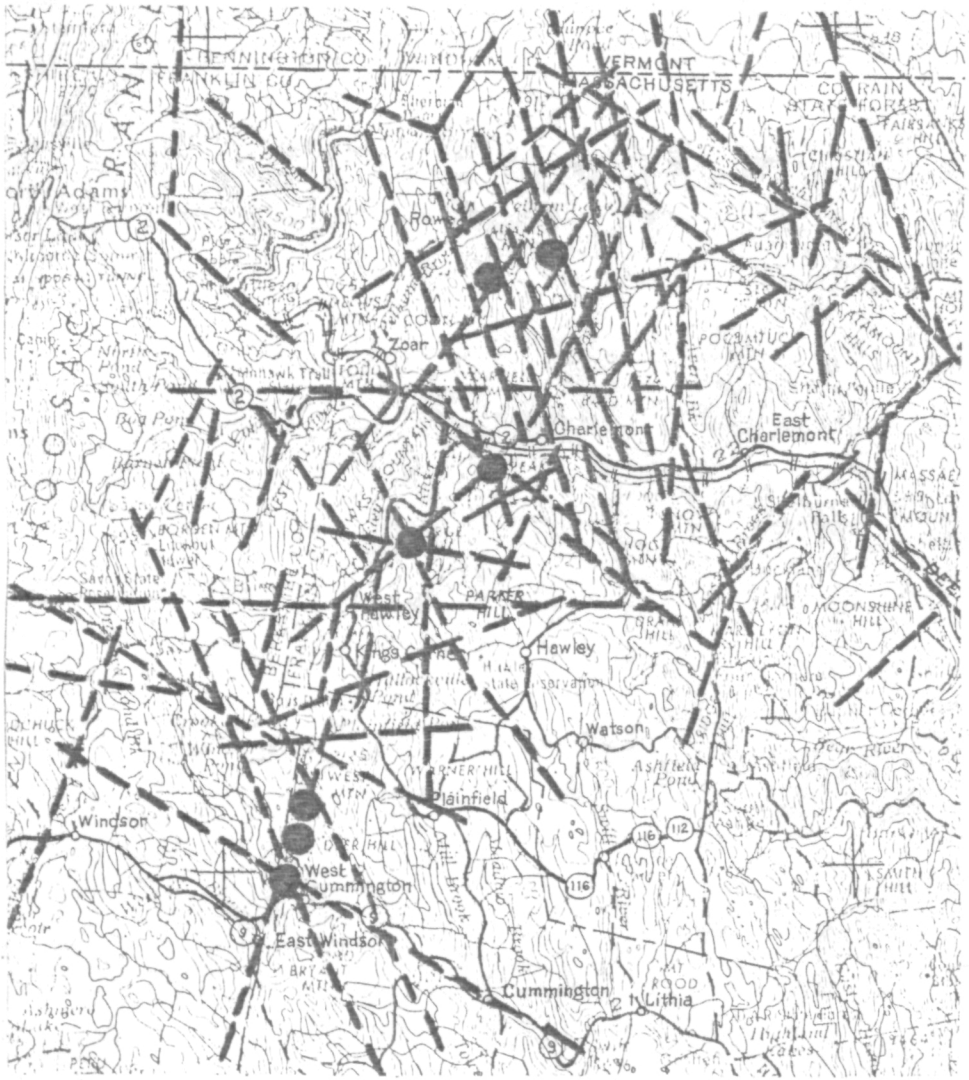


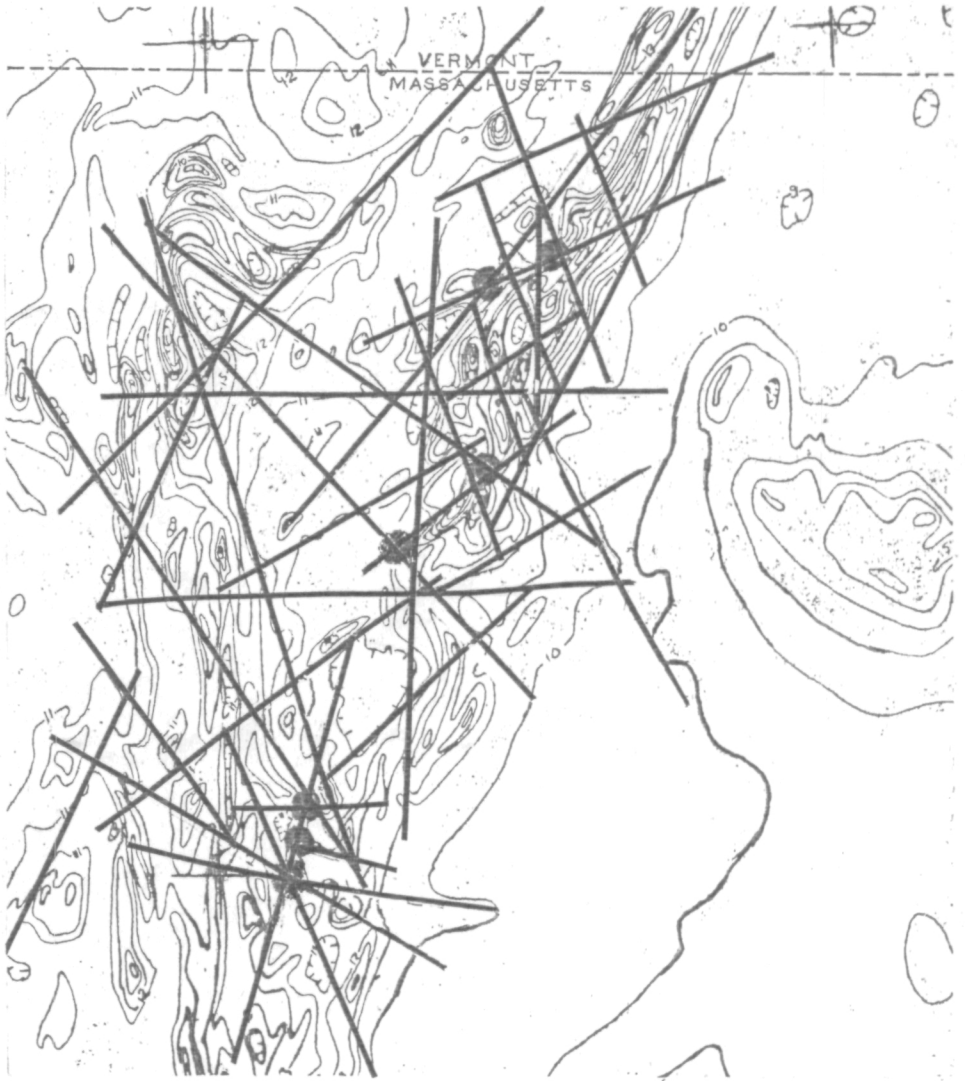
FIGURE 34: Bedrock geology and locations of mines and prospects, West Cummington and Charlemont area, Massachusetts. (From: A. W. Quinn, 1967, "Deposits of the 'Mineral Belt' of Western Massachusetts" in Economic Geology in Massachusetts).



1:250,000 Scale

FIGURE 35a: ERTS fracture-lineament (--) and mine location (●) map for the Cummington-Charlemont area, Western Massachusetts.

INDEX MAP



1:250,000 Scale

FIGURE 35b: Portion of a U.S.G.S. aeromagnetic map showing mine locations (●) and magnetic lineaments which correspond closely to the fracture-lineaments mapped on ERTS imagery.

"basement" rocks. Of special importance is the correlation between the ERTS lineaments and the aeromagnetic lineaments in the "mineral belt" area. More than 60 percent of the aeromagnetic lineaments strongly correlated with ERTS lineaments, suggesting that many of the ERTS lineaments are surficial expressions of basement fractures or faults. Such lineaments could be the avenues of ore or mineral migration when the deposits were formed by the upward movement of hydro-thermal solutions. If such is the case, the use of ERTS imagery and aeromagnetic data could be an important technique for locating additional ore prospects in this area or in similar geologic terrains.

5.6 Procedures for Using ERTS Snow Enhanced Imagery in a Geological Field Mapping Program

Procedures for the quasi-operational application of ERTS imagery to complement an active geological field mapping program in complex geological areas were established (Table 7). While the sequence of steps in any geological mapping program will vary from area to area and from geologist to geologist, the following summary should have general acceptability:

TABLE 7: PROCEDURAL STEPS FOR THE USE OF SNOW ENHANCED ERTS IMAGERY IN A GEOLOGICAL MAPPING PROGRAM

STEPS	INVESTIGATION STUDY AREA	PRODUCT
I. Review available geological literature and existing geological and topographic maps. Identify, catalogue and selectively acquire existing remote sensing records.	Presently being conducted as part of the U. S. Geological Survey (USGS) program in the area; investigators established contact with the USGS early in the project	Working File; Catalogue of Recent Remote Sensing Records.
II. Select base map scale and format for appropriate display of regional geological information.	ERTS imagery constitutes an effective base map for display of large quantities of geological information. Opinions from other investigators on map scale were solicited. ERTS photo base maps are a useful base for information display, in some instances a line map may be satisfactory.	Experimental Map Enlargements (which can serve as supplementary working field prints later). (see Step IV)
III. Acquire all ERTS imagery for the area and for all bands. NOTE: This step should be accomplished where there are no significant budget constraints. Where budget or time constraints exist, acquisition of an autumn snow-free set (MSS Bands 5 and 7) and all snow-covered imagery (MSS Band 5) is recommended.	All ERTS imagery was analyzed as part of this investigation. Particularly useful and abundant geological data was acquired from analysis of snow-covered imagery.	ERTS Catalogue of Coverage For Test Area
IV. Analyze ERTS imagery and prepare structural reconnaissance maps. NOTE: Snow-covered ERTS imagery provides early regional information concerning the structure of the area.	Following ERTS analysis and lineament validation a fracture-lineament (structural reconnaissance) map on a snow-free ERTS photo base was prepared to display all fracture-lineament detail derived from analysis of 70mm transparencies and 9.5 inch prints. This is a reconnaissance product intended to facilitate site analysis, and identify regional variations in lithology, age of tectonism etc.	Fracture-Lineament Reconnaissance Map (POCKET)

STEPS	INVESTIGATION STUDY AREA	PRODUCT
V. Conduct reconnaissance field observations throughout the area. NOTE: The map prepared above serves as the principal tool for field checking preliminary to intensive structural mapping. During the reconnaissance visit, a review of "type section" for each major tectonic unit preliminary identified within the area will be conducted. "Type locations" of the major structures will be surveyed; joint and lithological observations will be made.	Blueline proofs of the reconnaissance structural map were used in combination with ERTS enlargements (1:250,000) of snow-covered terrain for field checking. The ERTS enlargements were overlayed with a transparent snow-free Band 7 to facilitate location of water bodies useful for navigation and field positioning. Snow-enhanced imagery is otherwise difficult to use if water bodies are obscured by ice and snow cover. Band 7 emphasizes water bodies and to some degree road systems.	ERTS Field Navigation Maps and Methods.
VI. Technically revise and update the reconnaissance structural map. NOTE: The reconnaissance map can serve as a base map for geological notes.	A variety of field trips were made to the New England area resulting in revisions to the structural reconnaissance map. This a continuing process which would proceed systematically area-by-area for an operational mapping program.	Annotated ERTS Field prints; Field Observation Reports
VII. Conduct detailed area structural studies.	The nature and scope of detailed area studies will vary widely. Emphasis is placed on ERTS snow covered imagery. In this experiment, tectonic sketch maps were prepared to depict possible structural relationships. Several candidate tectonic sketch maps may be used to graphically express multiple variations of relationships as suggested by ERTS and complementary data.	Tectonic Sketch Maps
VIII. Acquire and analyze available remote sensing data of study areas	Aerial radar mosaics NASA ERTS underflight photography were acquired. Low altitude underflights were made by the investigators. Preliminary image analysis was conducted; major	Working Catalog and Image Library

	STEPS	INVESTIGATION STUDY AREA	PRODUCT
		structural trends, evidence of strategically located outcrops, various road and stream cuts, etc., were noted.	
IX.	Conduct field observation in areas of detailed mapping.	Numerous bedrock joint readings were acquired within the test sites. Observations of topographical alignments, lithological variations, etc. were completed.	Field Joint Records; Sub-regional Polar Plots
X.	Initiate detailed geological mapping. Beginning at the "best type" sections or from adjacent published maps, extend contacts through the area using standard geological practices.	This is now being conducted by the USGS in its quadrangle mapping. Field geologists can conduct the mapping program using ERTS data for regional and detailed tectonic studies, and thus map with a new dimension of geological information. Various experimental maps can be prepared and validated with the benefit of complementary aircraft data.	Multi-sensor Analysis Approach; Test Site Analysis Bands.
XI.	Produce a preliminary map of detailed mapping area and resolve problems for final map. NOTE: Remote sensing data (particularly aircraft data) can play an important role in helping the field geologist extend contacts across areas, etc.	A multi-analyst approach to double-check results and resolve mapping problems has been conducted using ERTS (snow enhanced) enlargements.	Great Barrington and Canaan Mountain Fracture-Lineament Analyses (Photobase Maps)
XII.	Develop descriptive and graphic data concerning the geological history of the area; identify structural relationships (prepare structural sections), prepare lithological columns, and summarize the geological history of the area.	Routinely conducted by the USGS in the Massachusetts area.	Thematic Maps and Report

STEPS	INVESTIGATION STUDY AREA	PRODUCT
XIII. Evaluate economic geology, noting relationship of mineral deposits to major structure, current mineral production, former production, and reserve estimates as appropriate.	Routinely conducted by the USGS; not conducted in this investigation.	Thematic Maps and Report
XIV. Evaluate engineering and environmental applications of the mapped data. NOTE: Geologically hazardous areas, groundwater resources, excavation characteristics, etc., will be studied depending upon the scope of the project at hand.	Conducted locally by USGS; not conducted in this investigation.	Thematic Maps and Report
XV. Produce Final Map	Routinely conducted by the USGS; not conducted in this investigation.	Final Geological Map Product(s)

6.0 BENEFITS ANALYSIS

6.1 General Introduction

The investigators have identified a variety of benefits that can be realized from the application of ERTS snow enhancement techniques. For the purposes of this study, qualitative assessments have been conducted. Benefits have been broadly grouped into (a) applications benefits, i.e., those which primarily serve the user community and (b) NASA program benefits, i.e., those which further the understanding of the use of ERTS imagery and the data from future ERTS-type satellites.

6.2 Applications Benefits

The applications defined in this experiment have come from the utility of ERTS imagery as the primary data source and not from dependence upon large or small scale aircraft coverage. Aircraft coverage was employed primarily to evaluate the effectiveness of ERTS fracture mapping.

ERTS-derived fracture-lineament maps, which provide significant increments of detail beyond that on present existing geological maps, are now available for reference by field geologists in the Massachusetts-Connecticut area. Snow enhancement interpretation techniques may therefore contribute to the acceleration of regional geological mapping. Engineering geology applications such as highway corridor routing, bridge abutment, dam and reservoir location and subsurface excavation (tunneling) may also benefit from the use of these techniques. Fracture information, which is lacking or unconfirmed on existing geological quadrangle maps in many areas of New England, has been developed. Field personnel can now conduct mapping with additional background information from which complex structural relationships may be resolved.

For office use alone, photogeological fracture mapping can be accelerated by proper utilization of snow cover as an enhancement tool particularly in areas with subtle fracture expression. Greater fracture detail (than can be detected during other seasons) may be extracted during the winter largely because of the higher surface contrast which snow provides in the presence of the shadowing effect of low angle solar illumination. Mineral exploration programs can also benefit from the applied use of snow enhancement interpretation techniques. The operational use of these techniques by mining companies has been encouraged by the investigators; success has been experienced in that major mining firms are requesting information on the use of snow enhancement procedures.

Applications-benefits can be realized for environmental geology mapping. Mapping backlogs to meet county and regional requests for geological planning data exist in many states. Snow-enhanced ERTS imagery supplies information which is difficult or time-consuming to obtain during other seasons. Discrimination of thermal outfalls, burning landfills, mined lands, underground mine subsidence, and land use mapping are anticipated applications. Information from ERTS analysis will be supplied to State agencies to facilitate preparation of environmental geology maps. Environmental planning benefits may accrue from the new and previously unidentified information which snow enhancement provides.

With the encouragement of special user groups, commercial flying firms may extend the period (from snow-free into snow-covered periods) during which satisfactory images for geological mapping studies can be acquired. For geological field reconnaissance from light aircraft bedrock outcrops can be more readily located under conditions of differential snow cover, i.e. increased snow free/snow cover tonal contrasts.

6.3 NASA (ERTS) Program Benefits

Benefits to the ERTS program in terms of future satellite needs for geology were identified (Figure 36). ERTS wintertime imagery acquired in a systematic manner justifies repetitive ERTS coverage for geological applications. For geological studies, the interactions of snow cover, soil moisture content, and dynamic snow melt/accumulation pattern-provide incremental increases in geological data for a substantial period of time.

Largely because of this experiment, the value of snow enhancement is increasingly identified for multidisciplinary studies within the ERTS program. Snow cover has been observed to enhance geological features including glacial landforms, foliation and bedding, fracture-lineaments, as well as land use types and drainage patterns.

A low-cost system for obtaining ground truth information has been demonstrated. The investigators have designed and employed a cost-effective mail-based approach for obtaining snow depth data on a regular basis. This network supplied data which was utilized (1) to construct isopach maps used for evaluating the influence of varying depths of snow cover on fracture detectability, and (2) to determine melt/accumulation trends needed for assessing the condition of snow cover at the time of ERTS overpasses. A selected portion of the network was reactivated to report leaf fall and percentage of leaf canopy on the dates of autumn ERTS overflights. This type of system could serve NASA under other circumstances.

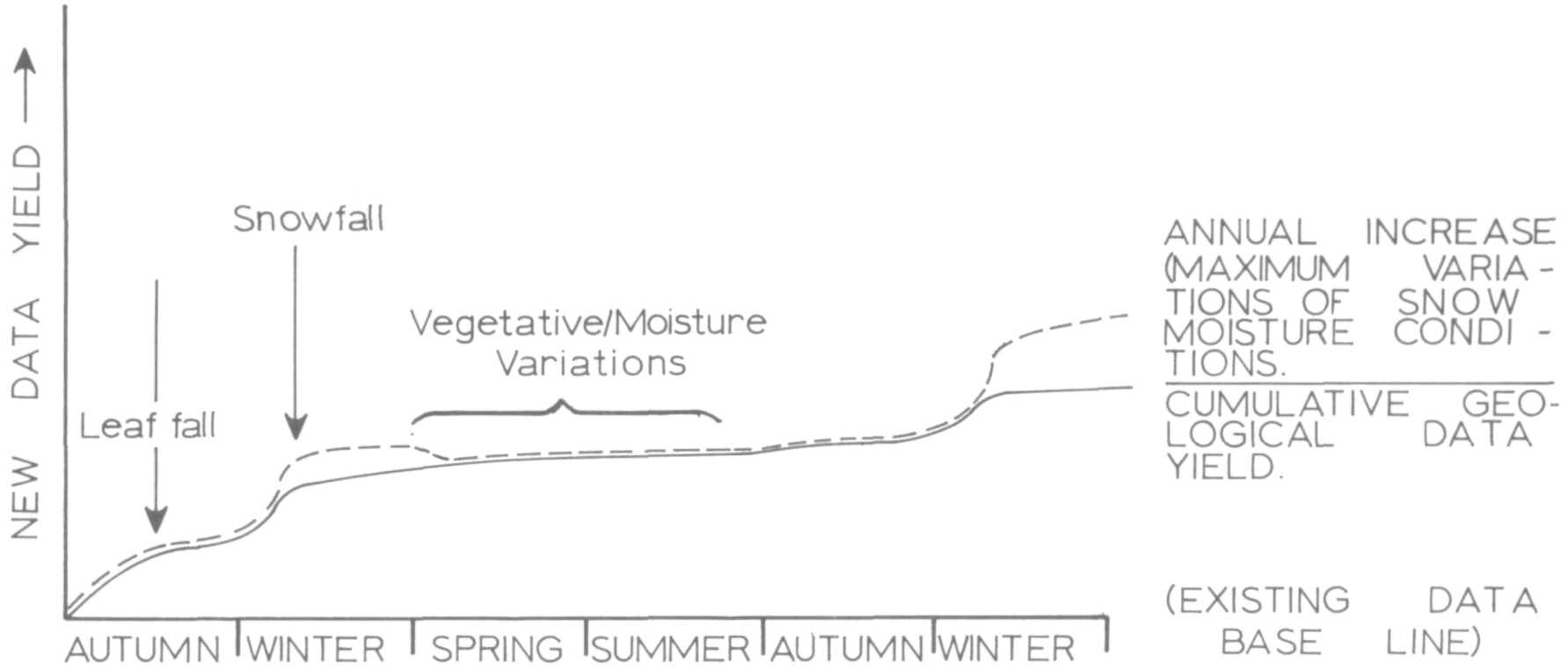


FIGURE 36: Seasonal contributions of new geological data. The geological data yield from ERTS analysis increases gradually over a period of time with major gains occurring during significant seasonal events including leaf fall, new snowfall, snow melt, etc. NOTE: Wintertime snowfall variations may increase geological data for an extended period of time.

Low sun angle snow-enhanced ERTS imagery often resembles SLAR imagery. ERTS imagery of snow-covered terrain without supporting aircraft coverage complements SLAR imagery by providing fracture-lineament data in areas of subdued topography. SLAR will not replace the geological data yield of ERTS imagery; there will be a continuing need for visible and near-infrared band ERTS systems.

A variety of additional benefits to the ERTS program realized by the applied use of snow enhancement techniques are suggested by the results of this investigation. These benefits are capsulized below:

- Evolution and development of the experiment within a short period from a research-oriented project toward a practical method for acquiring geological data.
- Development of snow enhancement techniques promotes more full utilization of wintertime ERTS imagery.
- The merits of the technique have been recognized by foreign countries (northern latitudes). Inquiries have been received on the availability of NASA imagery and technique development from many countries including Canada and Norway.
- Snow-enhancement techniques serve to effectively extend the resolution threshold of ERTS and other low resolution satellites.

7.0 RECOMMENDATIONS FOR FURTHER STUDY

The snow-enhancement techniques developed in this study have introduced a new philosophy for geological data acquisition to user groups. Principal emphasis should be given to demonstrations of the technique to user groups.

Several specific recommendations follow:

- Application of snow enhancement techniques to the preparation of map products in environmental geology. This investigation should be conducted using both ERTS-1 and ERTS-B imagery. Prototype maps will be prepared to display environmental geological information in a format usable by selected State planning agencies. Analyses conducted within the present investigation confirm that snow enhancement techniques will increase the usability of ERTS data for environmental geological studies and accelerate such mapping.

- Preparation of an excavation hazards map series for the Northeast Corridor utilizing snow enhancement techniques. The maps will be prepared in cooperation with the Department of Transportation and interested Congressional groups who have requested to be kept advised of practical ERTS applications.

- Extension of snow enhancement techniques to unglaciated terrains for geological studies.1/ The objective of this investigation would be to develop fracture information in unglaciated terrains of moderate to deep soil cover. Techniques to maximize fracture detection in complex geological terrains have been successfully developed from analysis of ERTS snow-covered imagery within the New England Test Area. The investigators believe that these techniques can be extended to facilitate the detection of fractures in areas of deeper, less permeable soils where fracture detail is difficult and usually impossible to obtain.

1/ A lack of measurable snowfall within the Maryland-Virginia allowed the investigators to make only preliminary observations needed for developing fracture analysis techniques for deep soil areas.

8.0 CONCLUSIONS

Investigation results and conclusions have come from the utility of ERTS imagery as the primary data source and not from dependence upon large or small scale aircraft coverage. This program is the first systematic analysis and demonstration of the value of snow enhancement interpretation techniques for acquisition of geological data and particularly with low resolution remote sensing records. A result of this investigation is the growing recognition of the value of snow enhancement for multidisciplinary studies within the ERTS program.

Snow-cover in combination with low-angle solar illumination provides increased tonal contrast of surface features and is especially useful for the detection of fracture-lineaments. Snow-cover also enhances other geological features including glacial landforms, foliation and bedding. Its effect is further emphasized by low angle solar illumination which emphasizes topographic expressions that are not as apparent on imagery acquired with a high sun angle. A difference of nine degrees (between 31 and 22 degrees) significantly augmented topographic shadowing in the presence of ground snow-cover.

For environmental geology applications, ERTS imagery of snow-covered terrain can contribute to rapid discrimination of thermal outfalls, soil variations and drainage patterns. Snow-cover increases the effective working resolution of ERTS imagery and aids in discriminating differing categories of land use (e.g., urban/rural boundaries, coniferous versus deciduous forest, etc.). Areas of snow-clearing, such as airport runways, highways and urban sub-areas, contrast more readily with their surroundings.

Snow-cover variations increase the detectability of lineaments and other geological phenomena because: (a) snow provides a homogenous cover to reduce minor soil or vegetative tonal variations which otherwise increase background "noise"; (b) snow increases the contrast of shadows resulting from slight topographic variations; (c) tonal contrasts between bare (snow-free), and vegetative (snow obscured) fracture traces and surrounding snow covered terrain are accentuated; and (d) snow melting is accelerated in moist zones and therefore provides an indirect measure of moisture/thermal properties serving to emphasize subtle lithological changes.

In general, heavy snow-cover (e.g. > 4 inches) accentuates geological features of major topographic expression; light snow cover (< 4 inches) accentuates fracture-lineaments, drainage patterns and land use differences. Of importance to the use of ERTS-imagery for geological investigations is that variations in snow-cover (and snow moisture content) will provide continuing opportunities for enhancement capabilities

from year to year. Monitoring melt/accumulation patterns should contribute unique geological data; small but continuing increments of geological data will be acquired annually.

The MSS bands most useful for the detection of fractures in both snow-free and snow-covered terrain are Bands 5 and 7. The preferred ERTS bands and analytical technique for fracture analysis are arranged in approximate order of increasing cost and analytical complexity (Table 7). Within the winter season, approximately 75% of fracture-lineament data can be acquired from MSS Band 5 and 7 visual image analysis of snow-covered terrain; other techniques provide only additional increments of information.

Black-and-white transparencies are judged to be slightly superior to prints for fracture detection and analysis. Color composites combine the best features of the two most productive MSS Bands 5 and 7, and are generally equal in geological data yield.

Of the various viewing techniques tested within this experiment, the film sandwich and additive color presentations supplied the greatest amount of linear detail. Isodensity processing enhanced vegetative alignments indicative of fracture control. The Ronchi grating was useful for accentuating macrolinear trends but tended to obscure subtle linear detail; thus, it defeated some of the unique benefits of snow enhancement. The value of computer (digital) techniques could not be determined because of the limited number of tests that were conducted.

Within the New England Test Area the same fracture systems were not as readily detectable in the spring, summer and fall as under winter conditions due to a lack of a contrasting ground surface medium (snow) and a relatively high sun angle. Comparable analyses of ERTS snow-free and snow-covered imagery resulted in a larger number of fracture-lineaments mapped from snow-covered imagery. In all comparative image sets, a greater total length of fracture-lineaments was mapped with the snow-covered imagery. Fracture-lineaments interpreted from multi-sensor imagery correlated well with the directions of bedrock joints mapped in the field, further supporting the geological validity of the mapped data.

Snow-enhanced ERTS imagery often resembles SLAR imagery in general tone and texture. ERTS imagery of snow-covered terrain without supporting aircraft coverage complements SLAR imagery by providing fracture-lineament data especially in areas of subdued topography and where the SLAR look angle lies in a quadrant other than that of the sun. SLAR does not replace the geological data yield of snow-enhanced ERTS imagery.

TABLE 8: PREFERRED ERTS MSS BANDS AND TECHNIQUES FOR FRACTURE ANALYSIS [1]

BANDS [2]	ANALYSIS TECHNIQUE
Band 5 (Snow Cover) [3]	Manual
Bands 5 & 7 (Snow Free)	Manual
Bands 4, 5, & 7 Color Composite (Snow Cover)	Manual
Band 5 (Snow Cover)	Film Sandwich
Band 5 (Snow Cover)	Isodensity Processing
Band 4, 5 & 7 (Snow Cover)	Additive Color
Band 5 & 7 (Snow Cover)	Digital Image Manipulation [4]

[1] Listed in order of increasing cost and complexity. The majority of analytical information may be obtained with the initial bands/technique.

[2] Formatted in prints, transparencies and/or CCT's

[3] Assumes conditions of snow depth which are known to enhance bedrock fractures (e.g., 1-4 inches).

[4] Not fully tested.

The utilization of aeromagnetic maps adds a new dimension to the photogeological analysis of snow-enhanced ERTS data. Coincidence of lineaments interpreted from ERTS imagery reinforces analyses of aeromagnetic lineaments in the search for mineralized fracture systems and dikes. The combined use of both tools can increase the speed and efficiency of mineral exploration and geological mapping. These data have been made available to the mining industry (Appendix F).

Variations in the number, spacing and orientation of fractures appear to reflect variations in tectonic activity within the test area. The potential for utilizing ERTS snow-enhancement for systematic fracture analysis as a means of detecting multiple periods of tectonic activity is great even in areas lacking widespread bedrock exposure.

The benefits to be derived from snow-enhancement of low resolution ERTS imagery have been proven. Snow-enhancement techniques have been integrated into a general operational procedure for conducting geological field mapping; sample products which represent interim steps in the mapping process (e.g., the ERTS Fracture-Lineament Reconnaissance Map) have been prepared. While it is recognized that opinions with respect to appropriate mapping techniques and procedures in geological programs will vary, the procedure cited should maximize the utility of snow-enhanced ERTS imagery and complementary aerial photography for a majority of geological mapping programs.

Benefits to the ERTS program in terms of future satellite needs for geology have been identified. ERTS wintertime imagery acquired in a systematic manner will provide successive increases in geological data yield from year-to-year. Geological phenomena are displayed differently with variations in the interactions between snow-cover, moisture content, and dynamic snow melt and accumulation patterns for successive winter seasons. Repetitive ERTS coverage for geology is justified.

Additional demonstrations of snow-enhancement will be required to encourage operational applications by potential users. A new concept for geological data acquisition has been proven which will benefit users of ERTS imagery.

APPENDICES

APPENDIX A

APPENDIX A

GLOSSARY OF TERMS

Ablation---------- Processes which reduce the depth of snow or ice cover including melting, sublimation and wind erosion.

Anticline---------- A fold, the core of which contains stratigraphically older rocks; it is convex upward.

Anticlinorium---------- A composite anticlinal structure of regional extent, composed of lesser folds.

Berkshire massif---------- A massive topographic feature in the Berkshire mountain range consisting of metamorphosed igneous rocks more resistant than those of the surrounding rock strata.

Fault---------- A fracture surface or zone in rock along which appreciable displacement has taken place.

Fold---------- A curve or bend of a planar structure such as rock strata, bedding planes, foliation or cleavage.

Foliation---------- A general term for a planar arrangement of textural or structural features in any type of rock.

Fracture---------- A surface along which loss of cohesion has taken place, i.e. a general term for any break in a rock including joints and faults. In this report the term is used to describe fracture traces (surficial expressions of subsurface fractures) as well as surficial fractures.

Glacial Drift---------- A general term for any material that has been transported by glaciers.

Fracture-Lineament---------- Structurally controlled features judged to be surface expressions of bedrock fractures. May represent a single fracture or series of closely spaced subparallel fractures.

Glacial Striae----------A series of long, usually straight and parallel furrows or lines inscribed on a bedrock surface by the gouge and scour of rock fragments embedded at the base of a moving glacier; usually oriented in the direction of ice movement.

Image Lineament----------A linear feature mapped from analysis of ERTS imagery which has not yet been validated.

Joint----------A surface of actual fracture or parting in a rock without displacement of either side relative to the other.

Metamorphic Rock----------Rock that has formed under conditions of high temperature and pressure, having an interlocking arrangement of mineral grains known as crystalline texture. Chemical rearrangements and changes in shapes of mineral grains have occurred without actual melting of the rock from which they formed. Metamorphic rocks commonly have mineral grains arranged parallel to each other. Examples include slate, schist, gneiss, marble and amphibolite.

Snow Dusting----------A very light, layer of snow cover.

Snow Enhancement---------- The accentuation of various phenomena on the Earth's surface resulting from the differential accumulation and/or melting of snow cover, or its obscuration by vegetative cover.

Snow Obscuration----------The masking of underlying snow cover from aerial sensors by varying densities of vegetative overstory.

Taconic Orogeny ----------A major period of late Ordovician tectonic activity in the Northern Appalachian mountains during which the rocks making up the Taconic mountains were thrust westward to their present position.

Test Area----------Regional areas (e.g., southern New England) which are analyzed to develop and refine a given hypothesis or technique.

Test Site----------Localized area of high geological interest within the test areas which receive intensive analysis.

Thrust Fault----------A fault with a dip of 45° or less in which the hanging wall appears to have moved upward relative to the footwall, characteristically with a horizontal compression rather than a vertical displacement.

Validation----------A deductive system for giving increasing or decreasing weight to a fracture-lineament using manual and/or electro-optical techniques.

APPENDIX B

APPENDIX B

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APPENDIX C

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APPENDIX D

APPENDIX D

SELECTION AND DESCRIPTION OF MARYLAND-VIRGINIA TEST AREA

Rationale for Selection of the Maryland-Virginia Test Area

The Maryland-Virginia Test Area includes portions of southern Maryland and northern Virginia. It extends from the Baltimore-Washington areas westward to Winchester, Virginia - Hagerstown, Maryland area. The Potomac River crosses the test area at nearly right angles to the regional structural strike providing nearly continuous bedrock exposure.

The Maryland-Virginia region was selected as a primary test area because (1) its physiography and bedrock geology is broadly similar to the New England Test Area, and (2) it has a markedly diverse surficial cover. This approach permits comparison of snow enhancement fracture detectability in differing soils over similar bedrock. The Maryland-Virginia Test Area is largely covered by residual clay soils from weathered crystalline bedrock. The bedrock of New England Test Area is mantled by relatively young, glacially-transported soils, which bear little or no relationship to the underlying bedrock. The fracture mapping in the Maryland-Virginia Test Area in impermeable clay soils contrasts with mapping in the relatively permeable glacial tills and morainal deposits of New England.

Maryland's complex bedrock geology (obscured by a deeply weathered mantle) introduces a need for geological information which is difficult to obtain by conventional ground mapping methods. The urban growth of Maryland provides a further requirement for more complete geological data, especially in the rapidly expanding urban fringe areas where considerable excavation and tunneling are being contemplated. The Maryland-Virginia Test Area would provide easy access and allow timely and direct observation of snow cover variations which would lead to an early understanding of the basic concepts of snow enhancement. The opportunity for rapid direct observation of ephemeral melt phenomena was an important factor in the selection of this area.

General Geological Summary of the Maryland-Virginia Test Area

The Maryland-Virginia Test Area extends from the Baltimore-Washington corridor westward to a line from Winchester, Virginia to just west of Hagerstown, Maryland (Figure 37).

The Potomac River roughly divides the area from northwest to southeast. The area includes portions of five physiographic provinces:

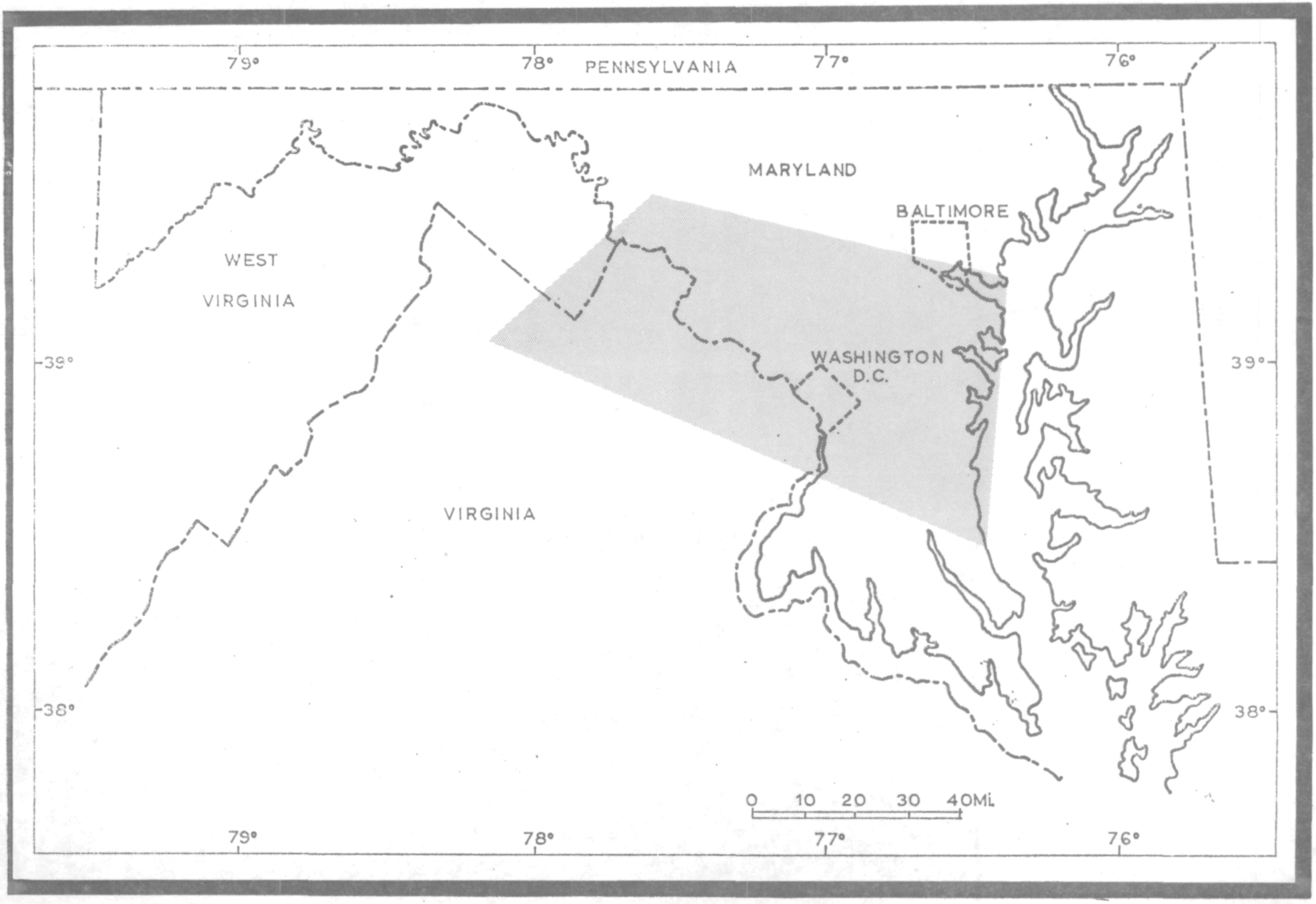

FIGURE 37 : Maryland-Virginia Test Area

(1) Atlantic Coastal Plain
(2) Piedmont
(3) Triassic Lowlands
(4) Blue Ridge
(5) Ridge and Valley

The Atlantic Coastal Plain is underlain by a series of southeasterly dipping beds of relatively unconsolidated Cretaceous, Tertiary, and Quaternary, clay, sand, and gravel. These strata were deposited on the eastward continuation of the crystalline rocks of the Piedmont. The unconformable surface between these two rock types also dips to the south east. The boundary between the Coastal Plain and the Piedmont is sinuous; it can be defined primarily by the erosion of the relatively soft Cretaceous formations which overlie harder crystalline bedrock (Cleaves, 1968). The boundary is best seen in the stream and river valleys where rapids and waterfalls have developed over the crystalline rocks at the edge of the Piedmont. The line connecting these rapids along the east coast is known as the "Fall Line" and marks the farthest upstream point of navigation.

The crystalline rocks of the Piedmont include highly metamorphosed sedimentary deposits including gneisses, slates, phyllites, schists, marble, and serpentine which have been intruded by masses of granitic and gabbroic rocks (Vokes, 1957). Because of the variety of rock types, their varied resistance to erosion, and their complex structural relationships, this region has a highly diversified topography. The western-most part of the Maryland Piedmont is underlain by a series of Cambro-Ordovician limestones that are folded but not strongly recrystallized, and upon which lie Triassic sandstones and shales of the Triassic Lowland.

No fossils have been found in the Piedmont metasediments. They have been so intricately infolded that their age and stratigraphic relationships are almost wholly a matter of conjecture. The Precambrian Baltimore Gneiss is probably the oldest rock in the Piedmont. Overlying it are the formations of the Glenarm Series, which include the Setters Quartzite, Cockeysville Marble, Wissahickon Schist, and the James Run formation. Higgins (1972) has interpreted the Setters, Cockeysville, and Wissahickon to be of Cambrian age and the James Run as Lower Ordovician. The Baltimore Gneiss is exposed in the cores of a series of large domes and anticlines. The Glenarm metasediments which occur along the flanks of these folds are part of a large anticlinorium.

The rocks in the western part of the Piedmont province are considerably less deformed than those to the east and are not intruded by granite and gabbro. The oldest rocks in this part of the area are the Wakefield Marble and a sequence of partially metamorphosed volcanic rocks that overlie it which are either older or equivalent to the Wissahickon

(Vokes, 1957). Overlying the Wissahickon are the Sugarloaf Mountain Quartzite, the Marburg Schist, and the Cambrian and Ordovician limestones of the Frederick Valley. The limestones lie in a predominantly synclinal fold belt that is fault separated from the other Piedmont rocks to the east (Cleaves, 1968).

The Triassic Lowlands are underlain by a series of sandstones and shales of Triassic age which are known as the Newark Group. These strata are part of a long belt that crosses New Jersey, Pennsylvania, Maryland, and continues southward into Virginia. The Triassic rocks lie unconformably on the Piedmont Crystalline rocks and dip westward into a large normal fault (Vokes, 1957). Numerous diabase dikes cut the Newark rocks. Two diabase sills also occur between the sedimentary beds in the basin.

The Blue Ridge Province consists of the Catoctin and South Mountains which unite to form the greater highland of South Mountain in southern Pennsylvania. The oldest rocks in this province are Precambrian granite-gneiss and granodiorite-gneiss which form the ancient core of the Blue Ridge or South Mountain Anticlinorium. These are overlain by younger Precambrian rocks of the Swift Run and Catoctin Formations. The Catoctin metabasalt is overlain by the Chilhowee Group of Lower Cambrian clastic rocks which are the basal strata of the folded Appalachians. The Chilhowee Group includes the Loudon argillite, Weaverton quartzite (probable western equivalent of the Sugarloaf Mountain Quartzite), Harpers Phyllite, and the Antietam Quartzite (Cleaves, 1968). The Blue Ridge Anticlinorium is a major structural feature in Virginia, Maryland, and Pennsylvania and separates the miogeosynclinal sedimentary rocks of the Appalacians from their eugeosynclinal facies equivalents in the Piedmont.

The Ridge and Valley Province lies west of the Blue Ridge and consists of a series of broad valleys underlain by relatively soft Paleozoic carbonates and shales which are separated by northeasterly-trending ridges upheld by sandstones and quartzites. These Paleozoic strata range in age from Cambrian to Pennsylvania and are folded into a series of elongate anticlines and synclines. Large and small thrust faults cut many of the folds and have moved older strata westward over younger strata.

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APPENDIX E

Instructions to Snow Depth Observers

Dear Cooperative Observer:

Your expression of interest in participating in our ERTS experiment is appreciated. Presently, the ERTS-1 satellite is relaying imagery of quite excellent detail although the initial three overpasses of the New England area have been somewhat cloud covered.

Soon after you receive this letter, you will also be receiving a supply of Snow Depth Reporting Postcards, pre-addressed to Earth Satellite Corporation. The cards are very similar to the Example Reporting Postcard which you received with the introductory letter. The next overflight of the ERTS-1 satellite will be on October 27, 1972. It would be appreciated if you could make your first measurement on or close to this date if you have received your supply of snow depth reporting postcards in time, and if snow cover is present in your area.

In the introductory letter, we indicated that we would like to have snow depth data reported on a weekly basis. Readings taken towards the middle of the week (on about Wednesday) would be most desirable. A list of dates indicating when the ERTS satellite will overfly the New England area is also enclosed. When these dates occur, readings should be taken on them in place of the weekly Wednesday reporting time. However, again we stress that the readings should be made when convenient to you. A difference of one or two days in reporting time may not be critical. The readings may be made during the day or night. Postcards may be mailed as soon as possible after you have recorded your measurements.

A few questions have arisen concerning the four topographic situations. First, let me reiterate that it is not necessary for readings to be taken in all four situations. A reading at one situation will satisfy our minimum needs. However, if readings can be readily obtained at more than one situation, it will furnish us with information of added value. It has also been mentioned that different situations would necessarily entail different locations and therefore, different latitudinal and longitudinal coordinates than those presently listed for your station. While this is entirely true, we are only interested in dealing with coordinates in degrees and minutes and are not concerned with coordinates to the nearest second. Thus, readings taken up to 1/10 of a mile from your present station location, would be sufficiently accurate for our purposes. The station number and name on the postcard

refer to your number and name within the National Weather Service reporting network as recorded in the monthly publication "Climatological Data" for the New England area. Since some stations report for several different networks, there has been some confusion as to which number should be used on the snow depth reporting postcard. Stations that have names appearing in the Climatological Data for New England may identify their number (index number) on the attached xeroxed sheet. Use of this four digit number on your snow depth reporting postcards would help us in assembling the snow depth data. Stations that do not have names appearing on the sheet should leave the space for station number blank. These stations will be identified using the observer's name, geographic location or telephone number and their data recorded with that of the other stations. Telephone numbers, which could be written in the remarks section of the postcard, may be particularly useful in identifying these stations.

Your continued interest and support in our experiment is greatly appreciated. Please feel free to contact us if any questions arise or if additional clarification is needed on topics discussed in this letter.

Sincerely yours,

Frank J. Wobber
Director
Geosciences and Environmental
Applications Division

Enclosures
FJW/kw

ERTS OVERFLIGHT/SNOW DEPTH REPORTING DATES

FOR MASSACHUSETTS AND CONNECTICUT

1972

October	27
November	14
December	2
December	20

1973

January	7
January	25
February	12
March	2
March	20
April	7
April	25

APPENDIX F

SNOW DEPTH REPORTING POSTCARD

Observer:_____ Station Name:_____

Location:_____
(County) (State)

Station Number	Snow Depth - Inches (average)	Location	Observation Date (numerical)
	___inches on...	Hilltop	
	___ " on...	Hillside	
	___ " in...	Valley Bottom	
	___ " on...	Plain (level area)	

Remarks:

Snow cover for accentuating geological fracture systems—a new photogeological technique

By **Frank J. Wobber** and **Kenneth Martin***

Figure below is an Apollo-9 color infrared (CIR) photograph taken at an altitude of 125 nautical miles over the Globe, Arizona, United States, area on March 12, 1969. The approximate photographic scale (1:1,000,000) and level of detail are comparable to imagery anticipated from the Earth Resources Technology Satellite (ERTS-A). Geographic reference points shown on the photograph include the town of Globe, Arizona (G), the Superstition Mountains (M), Theodore Roosevelt Lake (TL) and San Carlos Lake (SL).

The photograph demonstrates the value of snow cover as an enhancement technique for detecting fractures and other features (note circular feature, lower right) of possible interest to the mineral exploration community. Analysis of this and small scale aerial photographs indicate that snow cover (and probably the monitoring of snow melting) enhances subtle topographically expressed lineaments as well as fracture traces. Fracture traces are the surface expression of fractures covered by weakly consolidated sediments or soils. Fracture traces are photographically expressed as bare ground areas (dark photographic tones) which starkly contrast with the white tones of surrounding snow-covered areas. The detectability of subtle lineaments is reduced because this tonal contrast is not evidenced in snow-free areas.

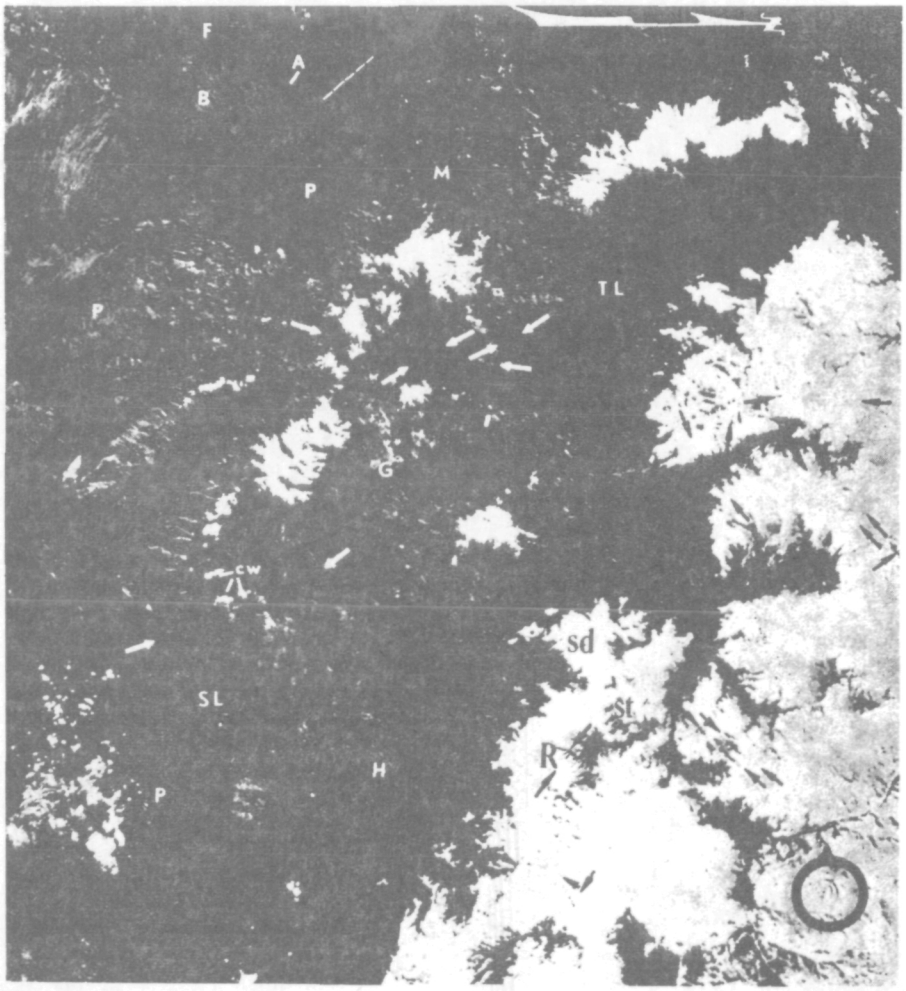
Within the snow-covered area, selected lineaments, which appear to be fracture traces or faults, have been mapped (black arrows). These lineaments are easier to detect within the snow-covered compared to the snow-free area. The primary cause for this enhancement effect appears to be variations in melting rates which occur over materials of different lithology and/or permeability. Fractures and faults generally have higher permeabilities than surrounding areas and can store moisture and raise their heat capacity so that freezing does not occur as quickly. New snowfall therefore melts off rapidly.

A comparative interpretative effort in snow-free versus snow-covered areas (white arrow) was conducted to identify significant lineaments. Fewer numbers of detectable lineaments were identified in snow-free areas assuming similar lithologies. This suggests that snow enhancement is a valuable tool in fracture detection and analysis. Not all lineaments detectable in snow-covered or snow-free areas are geological in origin. Man-made structures (e.g., transmission lines, pipelines, highways, railroads, etc.) may be confused with natural lineaments in analysis of small scale imagery. One such lineament (dashed line) which appears in the upper left of the photograph is a multiple lane-divided highway, U.S. 80-89. In close proximity to the highway are the checkerboard field patterns of irrigated croplands (F) near the Gila River. A thinly veneered pediment (P) grades into an alluvial apron or bajada (B) formed by coalescing alluvial fans. Other pediments and bajadas occur and can be identified from the photograph.

The problem of distinguishing snow cover from cloud cover is well exemplified in several areas on the photograph. Small areas of snow cover(s) could be difficult to differentiate from singular or wispy cloud formations. Cloud formations, however, are distinguishable in that they tend to obscure surface detail, cast noticeable shadows, and often have unique texture and form.

Tonal variations within snow covered areas suggest differences in snow depth, which may be a function of topographic obstructions, wind direction, solar aspect, or other factors

Continued on page 89



* Wobber and Martin are with the Geosciences and Environmental Applications Division, Earth Satellite Corporation, 1771 N. Street N. W., Washington, D. C., United States

APPENDIX G

APPENDIX G

HIGHEST QUALITY ERTS-I IMAGES: NEW ENGLAND TEST AREA[1/]

DATE Autumn	Image Identification
October 27, 1972	1096 - 15065
October 27, 1972	1096 - 15072
December 2, 1972	1132 - 15074 *
October 22, 1973	1456 - 15043
October 22, 1973	1456 - 15050
Winter	**Image Identification**
January 7, 1973	1168 - 15065 *
February 12, 1973	1204 - 15072 *
February 12, 1973	1204 - 15074 *
Spring	**Image Identification**
April 7, 1973	1258 - 15080 *
April 7, 1973	1258 - 15082 *
Summer	**Image Identification**
July 24, 1973	1366 - 15063
July 24, 1973	1366 - 15065

[1/] Other high quality scenes are available which contain portions of the Test Area. The selected scenes are those which are centered within the Test Area.

* Scene contains continuous or discontinuous snow cover.

TACONIC SYNCLINORIUM

GREEN MOUNTAINS ANTICLINORIUM

CONNECTICUT VALLEY GASPE SYNCLINORIUM

BRONSON ANTICLINORIUM

MERRIMACK SYNCLINORIUM

43°00′

NEW YORK

VERMONT

NEW HAMPSHIRE

NORTH ADAMS

GREENFIELD

CONNECTICUT RIVER

QUABBIN RESERVOIR

42°30′

PITTSFIELD

BERKSHIRE HIGHLANDS

MASSACHUSETTS

GREAT BARRINGTON

HOLYOKE

SPRINGFIELD

42°00′

CONNECTICUT

TORRINGTON

HARTFORD

HIGHLANDS

73° 30′

73° 00′

CONNECTICUT RIVER TRIASSIC BASIN

72° 30′

72° 00′

PREPARED FOR THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

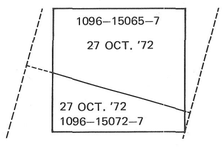
NASA Contract No. NAS5-21744

BY

EARTH SATELLITE CORPORATION

MAP BASE PREPARED FROM MULTISPECTRAL SCANNER IMAGERY ACQUIRED BY THE EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS). THE IMAGE, BAND 7, WAS ACQUIRED IN THE NEAR INFRARED (800-1100 nm) PORTION OF THE SPECTRUM. BECAUSE OF DISTORTIONS INTRODUCED BY THE SCANNING SYSTEM DURING IMAGE ACQUISITION, THE POSITIONING OF THE COORDINATES IS APPROXIMATE.

ERTS IMAGERY BASE SOURCE



FRACTURE - LINEAMENT MAP

FOR

WESTERN MASSACHUSETTS

And Surrounding Areas

Reconnaissance Map Prepared Primarily from Analysis of Snow-Enhanced ERTS-1 Imagery.

Map product prepared as part of the development of operational mapping procedures using snow enhancement techniques. Prior to using the map, users should refer to the report prepared for NASA which descibes investigation objectives and procedures.

SCALE 1:250,000

5 0 5 10 15 20 Statute Miles

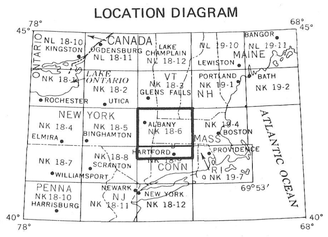
5 0 5 10 15 20 25 30 Kilometers

5 0 5 10 15 Nautical Miles

LEGEND

———	Fracture - Lineament	Confirmed by validation system
– – – –	Fracture - Lineament	Unconfirmed by validation system
———	Tectonic Boundary	From existing geologic maps
	Bedrock Joint	Primary and secondary joint directions measured in field

LOCATION DIAGRAM



FRACTURE–LINEAMENT VALIDATION

Fracture - lineaments are defined as structurally controlled features judged to be surface expressions of bedrock fractures. Linear features mapped from ERTS imagery were validated using a sequential system of upgrading or downgrading based on: consecutive image analysis by three photogeologists, geological maps, aeromagnetic maps and radar maps. Some fracture - lineaments were also validated by field observation. Topographic maps were checked to eliminate cultural data. Linear geological features such as bedding, foliation, and faults if identified from existing sources were omitted.